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HANDBOOK

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TEST METHODS

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PHILCO CORPORATION
PHILADELPHIA, PENNSYLVANIA

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DEPARTMENT OF THE NAVY
BUREAU OF SHIPS

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IN REPLY REFER TO
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21 February 1955

From: Chief, Bureau of Ships
To: All Activities Concerned with the Installation, Operation and Maintenance of the Subject Equipment

Subj: Handbook of Test Methods and Practices, NAVSHIPS 91828(A)

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Chief of Bureau

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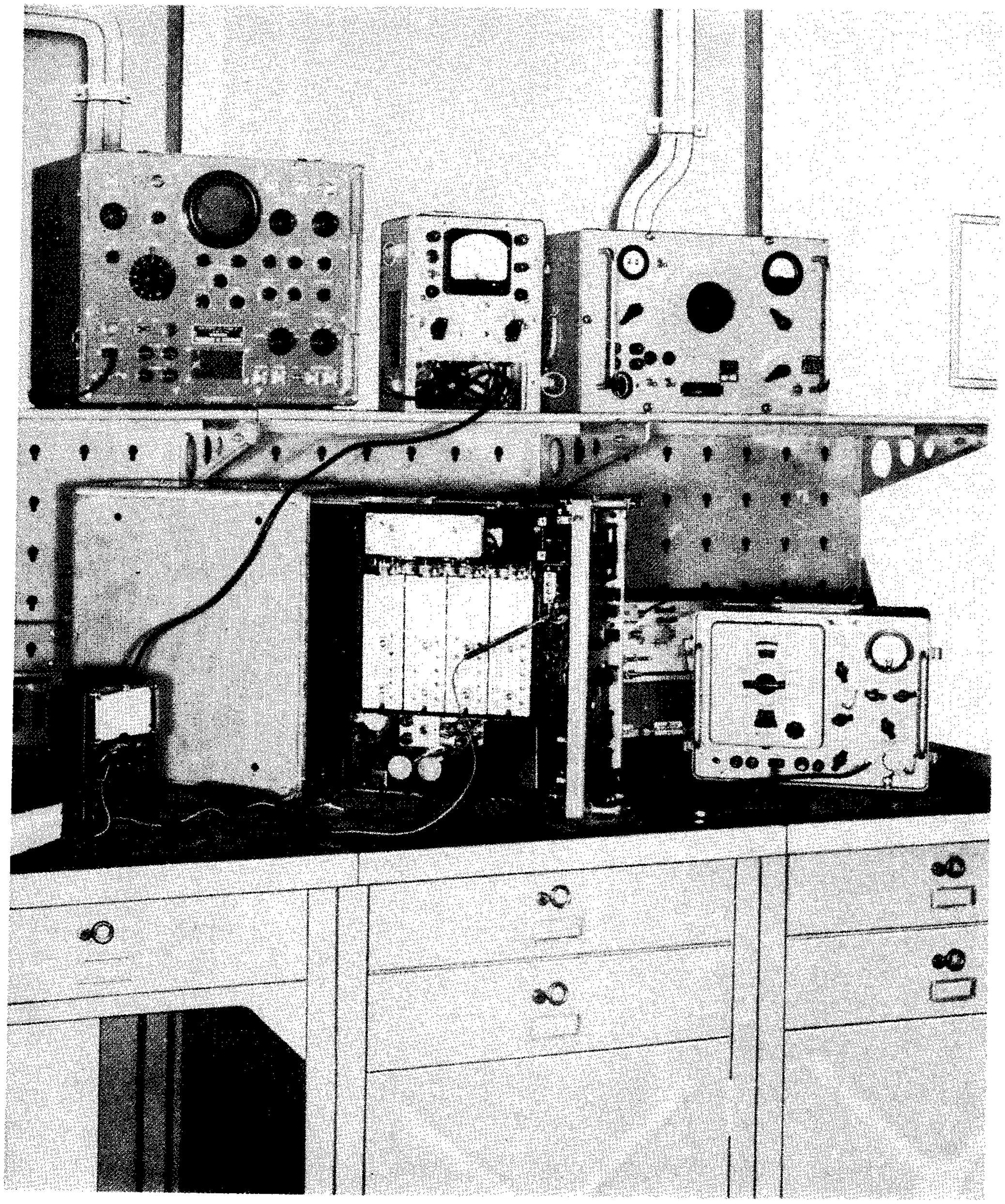


Figure 1-1. Typical Bench Test Setup

SECTION 1
TESTING IN GENERAL

1-1. PURPOSE AND SCOPE OF MANUAL.

This manual is written to meet the technician's need for a convenient, handy reference on the fundamentals of testing electronic equipment. The wide scope of the information, covering both theory and practice, makes the manual equally valuable for the beginning technician and the technician who has had years of experience. Many practical suggestions (kinks) and time-saving short cuts that have proven effective in the field are incorporated, to aid the technician in locating and correcting equipment trouble in the minimum amount of time. The manual has been reviewed by technicians in ships, shops, and in schools in order to make it as effective as possible.

Section 1, Testing in General, discusses the importance and functional divisions of testing, along with some associated testing information, and explains the need for various types of measurements, including systems testing.

Section 2, Test Equipments and Measurements, provides the technician with a sound background in test equipment circuit theory. With this background, and the information provided in Electronics Maintenance Bulletin Chapter 3, he will be able to select the most suitable test equipment for a particular job and to interpret correctly the data obtained. In addition, he will be better qualified in the use of both general-purpose and specialized test equipment, including the test circuits built into prime equipments. All of these abilities are important requirements for efficient performance testing and trouble-shooting.

Section 3, Testing—Techniques and Practices, covers in detail the specific procedures used in testing communications, radar, and sonar. In this section the selection of logical test points (pertinent to circuit theory), the correct interpretation of tests, the selection of suitable test equipments, and speed of performance are stressed as important requirements for efficient testing.

Section 4 deals with Preventive Maintenance and the Repair of Test Equipment. Preventive maintenance procedures, care of accessories and cables, proper storage of equipment, and periodic inspections are all considered as important to easy, rapid trouble-shooting. This section also includes a discussion of the different levels of maintenance.

Section 5 contains reference data such as a list of the terms used in the manual, tables of radio-frequency classifications and letter coded radar bands and use of a Smith Chart.

1-2. THE IMPORTANCE OF TESTING.

As a result of the tremendous expansion of the electronics industry to meet the needs of World War II and the postwar demand for developments affecting many phases of living, there exists today a great number of electronic equipments—all of which require maintenance to keep them in continuous operation. Testing, considered in a broad sense to include trouble-shooting, is the most important part of this maintenance. Figure 1-2 shows the functional relationship that exists between testing and the other necessary services that enter into general shipboard (technical) maintenance of electronic equipment. Testing is divided into measurements, tests, and checks. All three of these terms may overlap in meaning, depending upon their use and the results obtained. For instance a power output measurement and a frequency check constitute a test of the operation of a transmitter. Checks, as considered from the preventive-maintenance viewpoint, are routine (inspection) measurements and tests that are made to determine whether an equipment is operating normally. If faulty operation is revealed by these checks, the trouble is located by means of additional measurements and tests (trouble-shooting), and correction (repair) of the trouble is brought about. Thus, the maintenance of electronic equipment is efficiently performed by means of the auxiliary services, and continuous operation of that equipment is maintained.

1-3. FUNCTIONAL DIVISIONS OF TESTING.

The functional divisions of testing, as discussed in the following paragraphs of this section, are necessary to facilitate the operation and maintenance of electronic equipments which are normally encountered in the field by electronics and fire control technicians. These divisions also provide a logical approach to the theory of testing and to the study of test equipment circuits.

1-4. BASIC MEASUREMENTS.

Specifically, the basic electronic measurements involve the fundamental electrical quantities, voltage and current, and the inherent circuit (component) characteristics, resistance, capacitance, and inductance. In any circuit, the voltage and current are dependent for their distribution upon the latter three circuit characteristics; therefore, voltage and current measurements are an aid in determining circuit conditions and in the

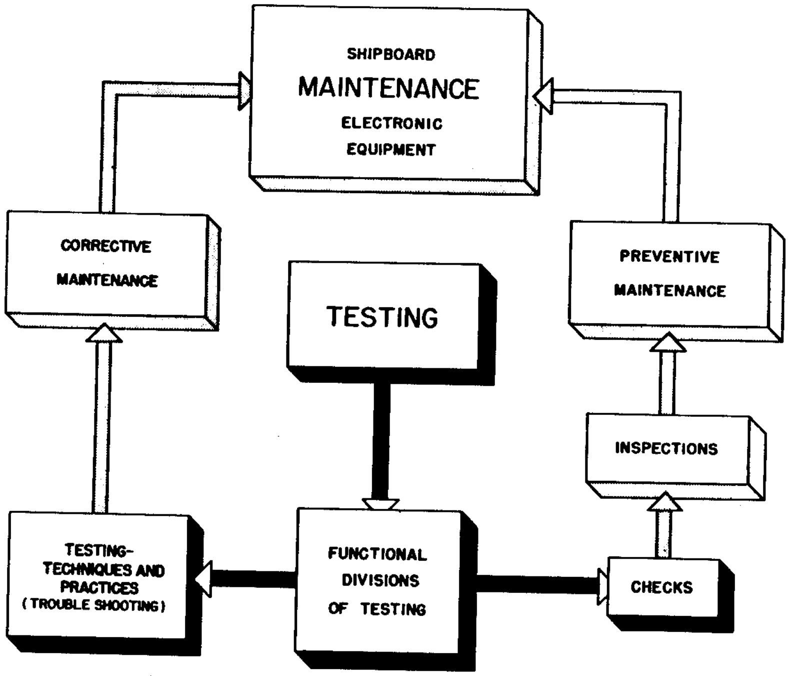


Figure 1-2. Functional Diagram of Shipboard Electronic Maintenance

evaluation of clues in the course of trouble-shooting.

Point-to-point voltage measurements, compared with available voltage charts, provide invaluable aid in locating trouble quickly and easily. However, if the sensitivity of the test voltmeter differs from that of the voltmeter used in preparing the chart, the voltage measurements must be evaluated before the true circuit conditions can be determined. The technician should keep in mind that in certain cases a voltmeter, particularly one of low sensitivity used on a low range, may disturb some circuits to such a degree as to render them inoperative.

As a rule, current measurements are not taken very often in the course of testing, unless the ammeter is an integral part of the equipment. Current measurements are infrequently used because in most cases the circuit must be opened (unsoldered) for the series ammeter connection; usually, a voltage measurement together with the use of Ohm's law is sufficient to show the circuit current. In a circuit of extremely high resistance, a current measurement is inadvisable because the current is so low that it cannot be measured accurately with ordinary test equipment.

Resistance measurements are valuable in locating trouble. Hence, many maintenance handbooks contain point-to-point resistance charts which are referenced to accessible points (usually tube sockets) within the equipment. Without these charts, resistance measurement in a complicated circuit is a slow process, sometimes necessitating the unsoldering of one side of a particular resistor (or group of resistors) in order to prevent erroneous readings as a result of shunting circuits which are not immediately apparent. It is important that the technician be acquainted with ohmmeters and the calibration of their scales, especially on the high ranges. Often it is impossible to attain reasonable accuracy when the meter is operated at its maximum range. For an ohmmeter, used for trouble-shooting, portability, convenience, and speed are considered to be of greater importance than extreme accuracy. Resistor tolerances vary so widely that approximate resistance readings are adequate for most jobs, with the exception of bridge circuits, voltage dividers, and balanced circuits. Two precautions to be observed when an ohmmeter is used are: the circuit under test must be completely de-energized, and any meters and tubes which may be damaged by the ohmmeter current must be removed before any measurement is made. It is not practicable to measure very low values of resistance with an ohmmeter, because of the excessive battery (source voltage) drain and possibility of damage to components under test. For precision measurement of low values of resistance, the bridge type of instrument should be used.

In the field, capacitance is usually measured by either a bridge- or a reactance-type capacitance meter. For accuracy, the former equipment is comparable to the resistance bridge, and the latter instrument is comparable to the simple ohmmeter. Capacitance tolerances vary even more widely than resistance tolerances, being dependent upon the type of capacitor, the value of the capacitance, and the voltage rating. Evaluation of capacitance tests is important, because, depend-

ing upon the circuit application, some capacitors might be rejected that otherwise would fulfill the requirements for that particular circuit. The power factor of a capacitor is important because it is an indication of the various losses attributable in the dielectric, such as current leakage and dielectric absorption. Current leakage is of considerable importance, especially in regard to electrolytic capacitors. The measurement of capacitance is very simple—the important point is that the technician know when to reject or continue to use a certain capacitor after it has been tested.

Inductance measurements are not made very often in the course of trouble-shooting. However, in some cases they are useful, and test equipments are available to make these measurements. As a rule most capacitance-measuring instruments can also be used to measure inductance. Most manufacturers supply inductance conversion charts for just this purpose if the test-equipment scale is not calibrated to read the value of inductance directly.

1-5. POWER MEASUREMENTS.

Measurement of d-c power presents little or no difficulty to the electronic technician; usually, Ohm's law can be applied along with a few simple circuit measurements. Such a-c characteristics as phase angle (power factor), reactance, etc., do not exist in a d-c circuit to complicate the measurement of power.

Low-frequency a-c power measurements also present no problem to the electronic technician. His duties do not, as a rule, extend to the recording or measuring of low-frequency (60-cycle) power. He is primarily interested in whether the proper a-c voltage is present for the input requirements of the various electronic equipments in use. However, as frequency increases, the need for a variety of power-measuring instruments and a knowledge of their operation and application becomes apparent.

In the audio-frequency range, power-level and power-output measurements have to be made in the course of routine maintenance. Power-level measurements are concerned chiefly with decibels (or volume units) (ratio changes of power), and working knowledge of these units is indispensable for proper interpretation of tests. The decibel is also used to indicate the power level in a circuit with respect to zero or a standard reference level. Receiver sensitivity tests are necessary after trouble-shooting and repair and as a performance check on receivers in operating condition. The limit (minimum discernible signal) of sensitivity is determined by man-made and natural atmospheric noises and noises developed or generated in the receiver itself. The latter category of noises is distributed more or less uniformly over the entire frequency spectrum. By adjusting the equipment to a narrow band of frequencies, the technician can increase the signal-to-noise ratio.

In the LF to VHF portion of the spectrum, the need arises (not very often at sea) to check transmitter output power. For this test, a common type of thermocouple ammeter is used in conjunction with a dummy antenna. The measurement of absolute transmitter output power is not often necessary—routine operating indications usually suffice to show transmitter performance.

In the UHF and higher portion of the spectrum, the measurement of r-f current, to calculate power, is not practicable. In this region, a power meter employing a temperature-sensitive element or a bolometer is used.

1-6. FREQUENCY MEASUREMENTS.

The setting of radio receivers and transmitters on an assigned frequency is an important task. This job is especially important when a major naval operation is planned, because surface ships, submarines, carrier-based airplanes, etc., are required to synchronize their separate movements by joint communications on frequencies on which absolute silence must be kept until contact with the enemy has been made. To aid the technician or radioman in this assignment, accurate frequency meters are made available to him. The calibration of these frequency meters is checked periodically against the primary standard frequencies transmitted by the U. S. Bureau of Standards from its radio stations in Beltsville, Md. (WWV) and in the Hawaiian Islands (WWVH). The primary standard frequencies are transmitted continuously (day and night), and several transmitters are employed to ensure reliable coverage of the United States and extensive coverage of other parts of the world. Pertinent information other than the transmitted frequencies, as listed in tabular form in Section 2, is also provided for any specialized application that the technician may encounter.

Extreme accuracy, such as provided by a frequency standard, is not always necessary or desirable in certain measurements. Where accuracy is not of prime importance, in making preliminary adjustments or for general experimental work, rapid frequency checks may be made with the simple resonant-circuit wavemeter. Since the wavemeter is relatively insensitive, it is very useful in determining the fundamental frequency in a circuit involving multiple harmonics.

In the ultra-high frequency range, the extremely small (physical and electrical) values of capacitance and inductance required for resonance make it necessary to use either a resonant-cavity or a resonant-coaxial-line type of wavemeter. Since it absorbs less energy from the circuit under test, this type of wavemeter is more accurate than either the reaction or absorption types, and, if it

is calibrated against a primary standard, it may be used as a secondary frequency standard.

Another method of measuring ultra-high frequencies makes use of a Lecher-line system. A meter is used to indicate the peaks (or nulls) of a standing wave that appears on a folded wire or bar (Lecher line) which is resonated to the particular frequency; then the distance between two consecutive peaks (or nulls) is measured to determine the wavelength. The wavelength is easily converted into frequency by means of a simple formula.

1-7. WAVEFORM MEASUREMENTS.

It is possible, by using a system of rectangular coordinates, to measure and view any recurrent phenomenon which involves a varying voltage. A periodic voltage which increases uniformly with respect to time is generally applied to the horizontal-deflection plates, while the voltage under observation is applied to the vertical-deflection plates.

Waveform measurements are very important, and are applicable to all electronic (and some mechanical) devices. It is necessary that the technician learn beforehand, either from existing instruction manuals or from previously recorded observations, the appearance of the waveforms which exist at strategic circuit points, so that by comparison he can determine whether the circuits are operating normally. However, all oscilloscopes have certain limitations, and a knowledge of these limitations is essential to the proper evaluation of the observed results.

Because of the low inertia of the electron beam, the oscilloscope is ideally suited for use in the analysis of fast-recurring phenomena, and is an essential test equipment for the rapid location of trouble in pulse-forming and amplifying circuits. However, an ordinary oscilloscope is inadequate for pulse analysis and observation. Such work requires the use of an oscilloscope that incorporates special circuits and refinements, such as voltage calibration and timing-axis calibration, to make it capable of more detailed and precise measurements. The uses of an oscilloscope of this type include the measurement and observation of peak-to-peak voltage, frequency response, linearity, phase shift, frequency, distortion, modulation factor, visual alignment, and transients. Special oscilloscope circuits (synchroscopes) will be discussed in this manual, to review for the technician the circuit elements involved.

1-8. MODULATION MEASUREMENTS.

When intelligence is superimposed on a signal, the process is known as "modulation." The characteristics which may be varied are amplitude, frequency, and phase. Each method of modulation has certain advantages over the others. However, at this point, the prime consideration is the measurement of modulation.

The carrier of radiotelephone transmitters should be so adjusted that efficient modulation takes place. When modulation is not sufficient, the carrier is not fully utilized; on the other hand, modulation in excess of 100 percent produces serious distortion. It is evident then, that either condition can result in ineffective transmissions. When possible, modulation should be maintained between 60 and 95 percent. Modulator gain should be initially adjusted by use of the oscilloscope method which is described later in Section 2. Two types of patterns are provided on the oscilloscope, depending on the hookup used. When connected to the tank circuit of the transmitter, the oscilloscope produces a pattern which has the actual shape of the modulation envelope. A different connection, which is explained in paragraph 2-9, produces what is known as a trapezoidal pattern. This type of pattern is more stable, and is used to determine the percentage of modulation. Test methods are also detailed in Section 2 and Section 3.

The increase of antenna current provides another method of modulation measurement, although this method does not show effects of phase shift or non-linearity. This is possible because the power delivered to the antenna increases with modulation, the added energy existing in the sidebands of the carrier.

1-9. STANDING-WAVE MEASUREMENTS.

A transmission line which is not terminated in its characteristic impedance is subject to a condition known as standing waves. Reflection of energy at the load end of the line gives rise to a wave that travels toward the generator end. This reflected wave varies continuously in phase in much the same way that the incident wave varies in phase. At points a half-wavelength apart, the two waves are exactly in phase and the voltage is maximum. At points a quarter-wavelength from the maximums, the two waves are in continuous opposition, leading to voltage nodes. Since the amplitude at such points is readily measured, it is convenient to call the ratio of maximum to minimum voltage the standing-wave ratio (VSWR). A similar ratio of currents will have the same value. A high SWR indicates a poor impedance match, and a low SWR indicates a good match. An SWR of 1:1 is optimum.

The measurement of VSWR has proved useful for the purposes of repair, preventive maintenance, checking and making adjustments. In radar work, a low SWR is maintained for the following reasons: (1) reflections in the line cause magnetron pulling and could result in faulty pulsing (this effect is more pronounced when the line is long compared to a wavelength);

(2) arc-over may occur at maximum voltage points; and (3) hot spots may occur in the line, and may lead to mechanical breakdown. In radar maintenance, SWR measurements are useful because (1) defective r-f line components may be located by checking the SWR of each component or by substitution, and (2) radars with r-f tuning adjustments may be adjusted with the aid of SWR test equipment.

1-10. FIELD INTENSITY AND NOISE (INTERFERENCE) MEASUREMENTS.

The magnitude of an electric field of a radio wave at a given point is known as the field intensity (or strength) of that wave, and is usually measured in terms of millivolts or microvolts per meter. The field strength of a radio wave is determined by measuring the r-f voltage induced in a receiving antenna.

Several types of test equipments for the measurement of field strength and noise (interference) are available to the technician in different ranges of frequency coverage. They are known as radio test sets, field strength meters and radio noise meters. With this type of equipment it is possible to measure either the relative or absolute magnitude of field intensity produced by an excited transmitter antenna. Using these test equipments, antenna efficiency, directivity characteristics, and signal coverage can be checked and compared. The test equipments also provide information which is useful in selecting transmitter antenna sites, making surveys of field intensities, and checking spurious harmonic radiation. Since the purpose of transmitter tuning controls and adjustments is to produce optimum radiation at the correct frequency, the field strength meter actually measures a part of the radiated field, thereby providing a true indication of the amount of energy being radiated. Interference, either radiated or conducted, can also be detected and located by the use of radio test sets.

The measurement of relative field strength can be made with rather simple test equipment; sometimes a grid-dip meter may suffice. Other test equipment circuits utilize a pickup antenna and a diode (or crystal), in connection with a microammeter, as discussed in detail later (Section 3). In circuits using the above combination, the meter reading indicates the relative strength of the field acting on the pickup antenna, and is not directly proportional to the field intensity because of the non-linearity of the crystal.

More elaborate test equipments for the measurement of absolute field intensity compare the voltage induced in a pickup antenna with a voltage generated by a self-contained calibrated oscillator. The antenna voltage is applied to a sensitive receiver which usually incorporates two calibrated attenuators, one between the antenna and mixer stage, and the other in the first i-f amplifier. An indicating meter in the test equipment shows the diode current in the second detector. This type of test equipment, discussed in detail in Section 3, indicates absolute field intensities, usually in terms of microvolts per meter.

When using field intensity measuring equipment, objects or persons near either the radiating source or the meter may cause shadows or reflections which result in erratic meter readings. The antenna of the test equipment should always be extended to its full length, to ensure proper operation of the tuning circuit. normal meter indications.

When the combination type of radio test set is used for detecting and locating interference or noise, the headset usually supplied with the test equipment is used. Two or more receptacles affording different amounts of amplification are provided for the headset jack. This permits the operator to select a comfortable audio level, depending upon the strength of the interfering signal and the proximity to its source.

1-11. ALIGNMENT OF TUNED CIRCUITS.

It should be clear that from a production standpoint it is impossible (or very impracticable) to manufacture electronic components without some variation in tolerances. It should also be understood that aging of parts, climatic conditions, vibration, etc., may cause the value of components to change. Because of the above conditions, variable components are provided in tuned circuits, so that, when the circuits are properly aligned, the optimum performance specified in the maintenance literature or by the manufacturer may be attained.

Reduced sensitivity or reduced volume of output generally indicates a need for alignment; however, this process should not be undertaken until the equipment has been put in good operating condition. Every equipment that is operating poorly requires maintenance, but it does not follow that every equipment that needs maintenance also needs alignment. In addition, repairs which require the replacement of components or the redressing of wiring make subsequent alignment necessary. Therefore, the technician should not attempt alignment until all troubles have been cleared and all defective parts replaced, so that time and effort will not be wasted on ineffective alignment beforehand. Furthermore, haphazard attempts at alignment by inexperienced or careless personnel may do more harm than good, and may increase the time spent on relatively minor repairs. It cannot be stressed too highly, that before alignment is attempted, all available instructional or maintenance literature should be carefully consulted. The above precaution results

in better job performance with less time and effort expended in the long run.

A sound knowledge of signal generators is necessary—their operation, circuit characteristics, modulator and output considerations. The principal purpose of a signal generator is to provide a known signal with adjustable characteristics. There is need, on occasion, for square or other nonsinusoidal waveforms, but, in general, test procedures require the use of sine waves of variable frequency and amplitude. Other test equipments are needed to examine the influence of the waveform furnished by the signal generator on the equipment under test. It is standard practice, for instance, to utilize signal generators for the purpose of trouble-shooting, aligning, or testing the over-all response of various circuits in electronic equipments.

The heart of a signal generator is an oscillator, the output of which may be varied as to frequency and amplitude. Less complex test equipments may omit a modulator and use a potentiometer as an attenuator, although the use of a modulator considerably increases the usefulness of the test equipment. Signal generators of advanced design may have several types of modulation available. Usually, the output attenuator is a single control calibrated for direct reading or a combination of fixed steps in addition to a continuously variable control.

Choice of frequency bands is usually made by switching appropriate coils into the circuits and the frequency within the band is varied by a tuning capacitor. Sometimes, a band-spread provision is included, so that particular frequency can be accurately selected by adjustment of an additional small capacitor. It is important that the selected frequency be reasonably constant and independent of the load connected to the test equipment.

The modulation frequency signal can be either fixed or variable. Generally, the source of the modulation frequency is an internal audio oscillator, but it is often desirable to modulate with a signal which is supplied externally. These signals may consist of a series of pulses or square waves, and are usually adjustable over a wide frequency range. When the modulation is variable, some means of indicating the percentage of modulation is usually provided.

The demands made on the output attenuator become more exacting when the frequency-range and accuracy requirements of signal generators increase. If a calibrating meter is used, it may be a bolometer type monitor meter that measures the current into the attenuator or an a-c electronic voltmeter which measures the voltage across the attenuator. A test equipment calibrated to read average value will not be affected by symmetrical modulation. If the meter is connected to a fixed calibration point, the output taps of the attenuator network can be labeled in volts, or, if the voltage is variable, as a fraction of the total.

1-12. TESTING OF ELECTRON TUBES.

It is generally conceded, as a result of accumulated experience, that approximately 50 percent of all electronic-equipment failures are caused by tube defects. In view of this fact, the testing of electronic tubes assumes considerable importance. It is possible to substitute a tube known to be good for a questionable one, and thus to determine the condition of the suspected tube. Indiscriminate substitution of tubes is to be avoided, as detuning of circuits may result. In addition, a tube may not operate properly in a high-frequency circuit, although it performs well in a low-frequency circuit. Therefore, if the technician is to service electronic equipments or systems properly, a knowledge of tube-testing devices, their limitations, and the interpretation of test results obtained, are indispensable to accurate and rapid job performance.

In order to determine the condition of an electron tube, some method of test is necessary. Because the operating capabilities (and design features) of a tube are shown by its electrical characteristics, a tube is tested by measuring its characteristics and comparing them with representative values established as standard for that tube type. Therefore, tubes which read abnormally high (or low) with respect to the standard are subject to suspicion. Practical limitations, which consider the accuracy of the correlation of the tube test with actual tube (circuit) performance, make it unnecessary to employ complex and costly testing equipment having laboratory accuracy. Since certain fundamental tube characteristics are fixed by manufacturing techniques, and since the accuracy of a tube testing device need be no greater than the accuracy of the correlation between test results and equipment performance, a relatively simple test can be employed to determine the serviceability of a tube. From the above considerations, it was found that the testing of a single tube characteristic generally suffices to determine whether or not a tube is performing satisfactorily. However, the selected characteristic must be such as to provide an over-all indication of the condition of the tube under test.

Testing the emission characteristic of the cathode (or filament) is perhaps the simplest method of determining the condition of a tube. The emission test is discussed in detail in Section 2. Emission often decreases as the tube ages; therefore, low emission is indicative of the end of tube serviceability. This test, however, is subject to limitations, because it tests the tube under static conditions and does not consider the actual circuit operation of the tube. Furthermore, coated cathodes (or filaments) often develop highly emissive

spots, so that the relatively small grid area adjacent to these spots cannot control the electron stream. Under these conditions, testing the total emission may indicate the tube to be satisfactory, while in reality it is defective.

From the definition of transconductance, it should be readily apparent that if this characteristic is tested the fundamental operating principle of the tube is also tested. It follows that when transconductance tests are properly made, better correlation between test results and actual circuit performance is obtained than is possible by the use of a straight emission test. There are two forms that the transconductance test may take—static or dynamic tests. Both tests are discussed in detail in Section 2.

To summarize, the technician should understand that a tube-testing device only indicates the difference between a given tube's characteristics and those which are standard for that particular type of tube. Since the operating conditions imposed upon a tube may vary over wide limits, it is not possible for the tube tester to evaluate a tube in terms of performance capability for all applications. Therefore, the tube tester is not considered the final authority in deciding whether or not a tube is always satisfactory. Inserting the tube in the equipment in which it is to operate, indicates best the condition of the tube. Nevertheless, the tube tester plays a very important part in indicating the serviceability of a tube. A tube tester can, in general, be used to determine whether a tube is unsatisfactory.

1-13. SYSTEMS TESTING.

Testing in the field of electronics serves a number of purposes. For example, measurements are indispensable for trouble-shooting and adjustment, test and alignment, and for experimental (laboratory) work. Also, reliable measurements are the only means of establishing compliance with those standards of frequency set by law. In addition, periodic testing can disclose any gradual decline in the quality of performance of an equipment or system, and can thereby help to prevent incipient failures.

Technicians are judged by their ability to maintain proper functioning of an equipment or system. Of course, when a system becomes faulty or fails entirely, he must of necessity make the required repairs. However, when the technician applies preventive-maintenance techniques (chiefly performance testing), he is in effect anticipating trouble. At first glance, the application of these techniques may seem like added work and effort with slight recompense; however, the opposite is true. By anticipating and correcting potential troubles before they fully develop, the necessary work can be performed in the normal work period or when the system is not required to be in operation; whereas, if a system failure occurs during operation or at a critical time, long hours of trouble-shooting under strain, and perhaps emergency repairs, may be necessary. It should be apparent to the electronic technician, then, that the acquisition of testing techniques of a preventive nature will, in the long run, lighten (by stabilizing) his work load, and will at the same time add to his reputation as a technician.

In conclusion, it should be evident that the maximum range, and, therefore, the tactical area covered by a radar, is primarily dependent upon the performance factor, or system sensitivity, and that this is controllable to some degree by the technical personnel assigned to the maintenance program. Consequently, it cannot be stressed too highly that the technician, along with improving his efficiency as a trouble-shooter, should be diligent in the application of the preventive-maintenace program.

SECTION 2
TEST EQUIPMENTS AND MEASUREMENTS

2-1. THE IMPORTANCE OF TEST EQUIPMENT.

A technician may be called upon to place new equipment in operation, perform routine preventive maintenance, or repair equipment. Many test equipments are available to help him to do these jobs efficiently. To place in operation and maintain new equipment, he is aided by test equipments such as signal generators, voltmeters, ammeters, frequency meters, and output meters. When there is a breakdown, volt-ohm-milliammeters, electronic voltmeters, signal tracers, electron tube testers, oscilloscopes, and other devices help to locate the trouble quickly and efficiently. It is true that most of these test equipments are generally complex; however, when analyzed, they can usually be reduced for purposes of explanation, into simple basic circuits. The following paragraphs of this section provide a review of both simple and complex test equipment circuits, and integrate the principles of testing with the test equipment involved.

2-2. METERS.

The galvanometer, developed and built by D'Arsonval, is still used today as the basis of modern meters. Because of its simplicity of design and construction, the galvanometer, with a few added improvements, still endures as a very useful laboratory test instrument. From this simple beginning there developed the present-day elaborate and complex test equipment.

There is an ever-increasing need for the intelligent measurement of electrical quantities. In fact, if the methods of making electrical measurements accurately and precisely had not progressed in proportion to other scientific developments, the field of electronics, as we know it today, could not exist. Since meters are usually the sensitive indicating devices for most test equipment, a thorough understanding of them—their construction, functions, and limitations—is a prerequisite to the intelligent measurement of electrical quantities.

a. TYPES OF METER MECHANISMS. — Three principal types of meter mechanisms are necessary, to meet the different conditions under which electrical measurements have to be made: (1) the permanent magnet-moving coil mechanism; (2) the stationary coil-moving coil mechanism; and (3) the stationary coil-moving iron mechanism. The operation of these three mechanisms follow certain basic principles covered in the study of elementary electricity.

(1) TYPE NO. 1 — PERMANENT MAGNET-MOVING COIL MECHANISM. — For electrical measurements the permanent magnet-moving coil meter movement is in universal use. This movement is based on the principle of the D'Arsonval galvanometer — a moving coil in a permanent magnetic field. The movement is constructed so that it is portable, and is provided with a pointer and scale for indicating the deflections of the moving coil. This instrument movement may be used as either an ammeter, a voltmeter, or an ohmmeter.

The essential parts of the meter mechanism are shown in figure 2-1. A permanent magnet, of the horseshoe type, provides the magnetic field in which the armature (electromagnet) rotates. Two soft-iron (curved) pole pieces are fitted to the magnet poles. A cylindrical soft-iron core is held between these pole pieces by a strip of brass or aluminum. This core provides a radial field, because a uniform air gap exists between the pole pieces and the core. The coil, consisting of very fine, silk-covered wire, is wound on an aluminum bobbin, which acts to produce a damping effect, because currents are induced in the aluminum as it cuts the magnetic field. The bobbin is supported, at the top and the bottom, by hardened steel pivots that turn in cup-shaped jewels. This method of support, which is practically frictionless, makes the instrument portable, as compared with the D'Arsonval galvanometer, in which the coil is suspended by a delicate filament. Current passes in and out of the coil through two spiral torque springs. Because these springs are coiled in opposite directions, temperature (also aging) changes cause the springs to set upon each other to pro-

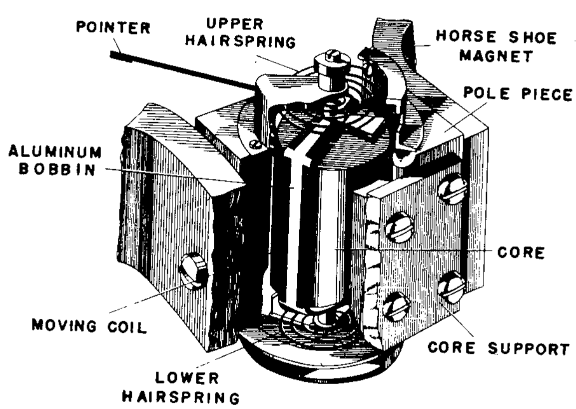


Figure 2-1. Meter Mechanism—Permanent Magnet-Moving Coil Type

duce a resultant force of zero, which tends to maintain the zero-set position of the pointer. The pointer is carefully balanced by very small counterweights, so that the moving element holds its zero position very closely, even if the instrument is not level. Because of the radial field, the amount of deflection of the pointer is practically proportional to the current through the coil, so that the scale of the instrument is substantially linear.

An electromagnetic coil, when placed in a permanent magnetic field, will try to move in a direction that depends upon its polarity relation to the magnetic field. The amount of deflection of the pointer, which is restrained by the action of the torque springs, is dependent upon the intensity of the current flowing through this electromagnetic coil.

(*a*) AMMETER ADAPTATION. — The intensity of current flow (dc) through the coil and through the torque springs limits the basic meter mechanism described above to a fixed range capable of measuring only fractions of an ampere. To overcome this limitation, and to protect the mechanism, a suitable auxiliary, the current shunt, is used. This device, which is actually a resistance of low value, permits the instrument to serve as a direct-current ammeter in the measurement of relatively large direct currents. That portion of the total current which cannot be safely conducted by the coil is by-passed through the shunt. The current reduction through the coil increases the current-measuring capacity of the instrument, and makes it possible to calibrate the dial accordingly. The instrument may be adapted to a variety of current ranges by the use of shunts of different values which are switched in or out as required.

(*b*) VOLTMETER ADAPTATION. — To make the basic meter mechanism suitable for measuring d-c voltage, another auxiliary, the voltage multiplying resistor, is added. The voltage multiplying resistor is placed in series with the coil, and limits the flow of current to a safe value. Also, since the value of the resistor is constant for any given application, the flow of current through the coil is proportional to the voltage under measurement. By proper calibration of the dial, the instrument is made to give voltage readings, although it is actually activated by currents. In practice, the voltage ranges of the instrument are established by the use of different values of multiplying resistors.

(*c*) OHMMETER ADAPTATION. — The ordinary ohmmeter is a device that utilizes a current-actuated meter for measurement of resistance values. It is used for practical work where simplicity, portability, and ease of operation are more important than a high degree of precision. It is possible to calibrate the dial of the current-actuated meter in terms of resistance, because a change in the resistance of a circuit will cause a proportionate change in the current flowing in that circuit, provided that all other factors remain the same. Meters are so designed that the deflection of the pointer is maintained very nearly proportional to the current through the meter coil.

There are two types of ohmmeters, the series type and the shunt type. With the series type, the resistance to be measured is connected in series with the meter. With the shunt type, the resistance to be measured is connected in parallel with the meter.

1. SERIES-TYPE OHMMETER.—For any given ohmmeter, mid-scale deflection (one-half the maximum deflection distance) is obtained when the current drawn by the meter is one-half the value of the current at full-scale (zero ohms) deflection, and this condition exists when the resistance being measured is equal to the total meter circuit resistance. Analysis of the circuit in figure 2-2 shows that full-scale deflection is obtained when the meter prods are shorted, and that less than full-scale deflection is obtained when the resistance to be measured, R_x, is connected into the circuit. If the meter now reads one-half of its former current, it follows that the total circuit resistance has doubled, indicating that R_x is equal to the total meter circuit resistance.

Since the ohms-calibrated scale is non-linear, the mid-scale portion represents the most accurate portion of the scale; however, the usable range extends (with reasonable accuracy) on the high end to ten times the mid-scale reading, and on the low end to one-tenth of the mid-scale reading.

To extend the usable high range of the ohmmeter, shunt R_s is removed from the circuit, and the value of series dropping resistor R_c is in-

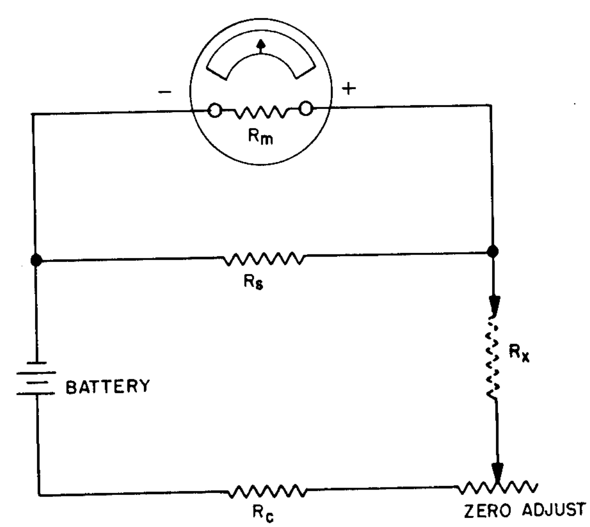


Figure 2-2. Series Type Ohmmeter—Basic Circuit

creased ten times. This now permits a mid-scale reading with a resistance of ten times R_x. The limitations which prevent a further increase in the usable high range of the ohmmeter are the fixed voltage (battery) and the sensitivity (current necessary for full-scale deflection) of the meter mechanism. A higher range can be obtained by increasing the battery voltage or by using a more sensitive meter mechanism. The former method is practical, and is used in some commercial test equipments.

It is possible to extend the usable low range of the ohmmeter by installing meter shunt R_s and decreasing R_c to a point where the current flowing in the circuit, and the internal resistance of the battery limit any further extension of the range. However, possible damage, due to excessive current, could result to components under test. It is also possible to extend the low range by decreasing the battery voltage, but this method is not practical; instead a shunt-type ohmmeter is used.

2. SHUNT-TYPE OHMMETER.—The shunt-type ohmmeter, as shown in figure 2-3 (its name is derived from the fact that the resistance being measured is shunted across the meter) is primarily used for the measurement of low and medium values of resistance. The shunt-type ohmmeter can be recognized at once by the fact that the scale is calibrated in the reverse direction as compared with the series type, and that full-scale deflection is obtained with the prods open. Midscale deflection occurs when the sum of the meter resistance and the shunt R_s is equal to R_x, the resistance to be measured. Limitations which prevent a further decrease in the range are: the internal resistance of the battery, which becomes an appreciable part of the total circuit resistance, causing errors in readings to increase with battery age; the excessive current drain, which decreases the life of the battery, and which could, in some cases, cause damage to components under test. However, it is definitely impractical to attempt to measure with an ohmmeter very low values of resistance. The ohmmeter, in itself, is only a means of approximating resistance values, where practical electronic work requires a convenient and speedy method of checking resistances. For precise measurement of low values of resistance, a test equipment utilizing the bridge principle is generally used.

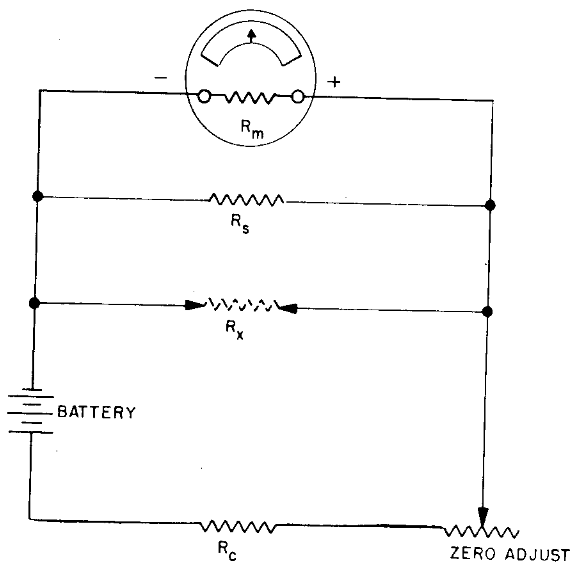


Figure 2-3. Shunt-Type Ohmmeter—Basic Circuit

(*d*) A-C ADAPTATION.—The permanent magnet-moving coil meter mechanism, as mentioned before, can be used to measure only d-c current and voltage. In order to adapt this mechanism for measuring a-c current and voltage, a rectifier or a thermal converter must be used as an auxiliary to convert the alternating current or its heating effect to direct current.

1. RECTIFIER. — The copper oxide type of rectifier used on many commercial meters, is compact, and has reliable accuracy for alternating waveforms with frequencies of 50 to 20,000 cycles. Each rectifier plate in the rectifier assembly is made of copper with one side bare and the other coated with a layer of copper oxide. Plates of this character offer a high resistance when current seeks to flow in the copper to copper oxide direction, and a very low resistance when it flows in the direction of copper oxide to copper; as a result, the alternating current is converted to direct current, and in that form is delivered to the meter mechanism. Copper oxide rectifiers are most commonly connected into full-wave bridge, double half-wave, and half-wave circuits.

At this point, it is important to consider how the calibration of the meter is affected by the use of a rectifier. The permanent magnet-moving coil mechanism responds only to the average value of the current, which is not necessarily the same as the effective value, which we want the meter to indicate. Waveforms of various shapes have different average and effective values. Since this type of meter mechanism responds only to the average value, in order for the instrument scale to read in terms of effective value, the shape of the waveform must be taken into consideration when the meter is calibrated. Thus, the meter reading will be correct only on waveforms for which the meter was originally calibrated. In this respect, therefore, the instrument has a definite limitation because even in conventional circuits waveforms may vary considerably. For example, the sine-wave voltage response of a half-wave rectifier will be 32 percent of maximum for the average value and 50 percent for the effective value. The full-wave rectifier response will be 64

and 71 percent respectively. In the design of the meter these values are taken into consideration and the scales plotted to read in effective units when calibrated against an accurate secondary standard.

2. THERMAL CONVERTER. — The thermal converter, utilizing the heating effect of the alternating current to generate direct current for the meter, does not have the limitation imposed upon the copper oxide rectifier by waveform shape. The average value of the direct current is equivalent to the effective a-c value, so that an instrument of this type, calibrated on dc, automatically reads the effective value of any a-c current, regardless of waveshape.

Physically the thermal converter consists of two dissimilar metal strips (usually antimony and bismuth) which are connected together and receive at their junction the heat generated in an element by the current to be measured. The two metal strips deliver to the meter a relatively small d-c potential produced as a result of the heating action. This d-c potential, however, produces current sufficient to operate the meter movement.

Since the heating effect of current is used, thermocouple ammeters are somewhat sluggish as compared with other meters, and require a certain warm-up period before accurate readings can be obtained. The scale is non-linear unless a specially designed meter movement is used. One very common use of the thermocouple ammeter is for the measurement of radio-frequency currents.

(2) TYPE NO. 2 — STATIONARY COIL-MOVING COIL MECHANISM. — The mechanism of the second basic type of instrument resembles that of the first in that a moving coil, through which flows the current being measured, reacts against a fixed-position field, as shown in figure 2-4, to produce a deflection of the pointer. The fixed-position field is furnished by two stationary field coils, which are rigidly mounted in the instrument assembly. Since the moving coil is placed directly between the two stationary coils, it rotates when the same kind of current is applied to both the moving coil and the stationary coils. Rotation, of course, is the result of the tendency of the moving coil to align its polarity with that of the stationary field. From this, it should be apparent that ac can be measured directly with this type of mechanism without first having to rectify it. In this mechanism (known as an electrodynamometer) both elements, moving and stationary, are energized by the same a-c source. Hence, the polarity reversals of the stationary coils occur simultaneously with those of the moving coil. The net result, as far as field interaction is concerned, is the same as though no changes in current direction were taking place, and the resultant pointer deflection is in one direction only.

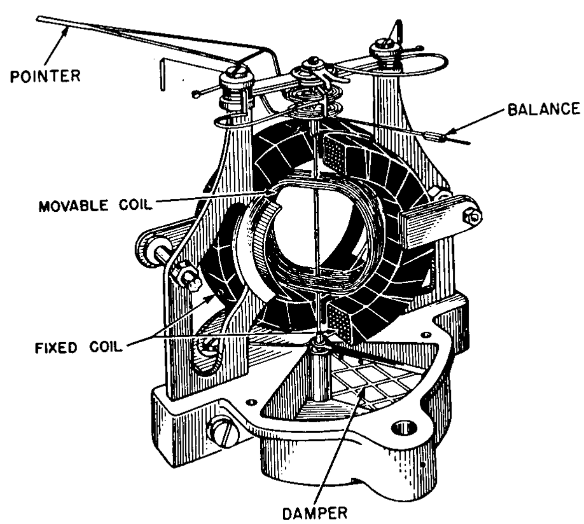


Figure 2-4. Meter Mechanism—Electrodynamometer Type

(a) POWER MEASUREMENT. — The dynamometer type of instrument, having a two-coil system, is primarily used for the measurement of power, because one coil may be energized by current and the other by voltage to produce a resultant pointer deflection that is proportional to the watts expended. Although in a-c circuits the current may lead or lag the applied voltage, with this type of instrument the power factor (unity or less) need not be considered, because the pointer deflection will represent—not the value of voltage times the total current—but the value of voltage times only that part of the total current which is in phase with the voltage. In other words, the instrument reads the true power expended (watts) rather than the apparent power (volt-amperes).

(b) CURRENT AND VOLTAGE MEASUREMENTS. — When the electrodynamometer is used to measure watts, as discussed above, a voltage multiplying resistor normally is connected in series to limit the current through the moving coil to a usable and safe value. The same mechanism can be used to measure either current or voltage separately as required. For voltage, the stationary coils and the moving coil are series connected with the voltage dropping resistor, the voltmeter is then placed across the voltage to be measured. For current, the voltage multiplying resistor is removed and a shunt is installed across the series connected moving and stationary coils; the ammeter, of course, is connected in series with the current to be measured.

(c) PHASE ANGLE (POWER FACTOR) MEASUREMENT. — This use requires a modification of the fundamental dynamometer mechanism. In the phase angle, or power fac-

tor, meter the moving element consists of two coils, which are mounted at an angle to each other. Also, the springs (three in number) exist primarily to carry current rather than to exert a torque. The moving coils are connected together at one end, and current is fed to them by their respective springs. The feed spring of one coil is connected in series with a reactor across the line, and the feed spring of the other coil is connected in series with a resistor. Current flow through the reactor-connector coil is approximately 90 degrees out of phase with the line voltage. The stationary coils are connected into the line in the same manner as an ammeter, thus creating a fixed-position magnetic field. Under these conditions, the moving coils will adjust themselves to the stationary field in a manner dependent upon the phase relationship of the line current and voltage. If the line current is in phase with the line voltage, the resistor-connected coil determines the deflection of the pointer, but if the line current and voltage are out of phase, the reactor-connected coil exerts an influence to correct the pointer deflection. For each degree of displacement between current and voltage there is a corresponding position of the moving element, and the pointer of the instrument indicates either phase angle (lead or lag) or power factor, or both, depending upon how the meter is calibrated.

(*d*) FREQUENCY MEASUREMENT. — A variation of the circuit described in the preceding paragraph is used to measure frequency. The resistive leg of the coil is removed from the circuit. Connected to either end of the stationary coils, a capacitor and an inductor are joined together, and the junction is connected to one side of the voltage source whose frequency is to be measured. The other side of the voltage source is connected to one lead of the movable coils, which are series-connected, and the other lead from the movable coils is connected to the center junction of the stationary coils.

Since capacitance reactance varies inversely, and inductive reactance varies directly, with frequency, an increase of frequency causes less current to flow in the inductive leg of the circuit and more current to flow in the capacitive leg. A decrease in frequency causes the circuit to act conversely. Hence, a change in frequency causes one stationary coil to receive more (or less) current than the other. This unbalance causes the meter pointer to deflect in either direction from a calibrated center point. Thus for each frequency over the measurement range involved there is a definite position of the pointer.

(3) TYPE NO 3. — STATIONARY COIL-MOVING IRON MECHANISM. — The third basic type of instrument mechanism resembles the second type in that a stationary coil is com-

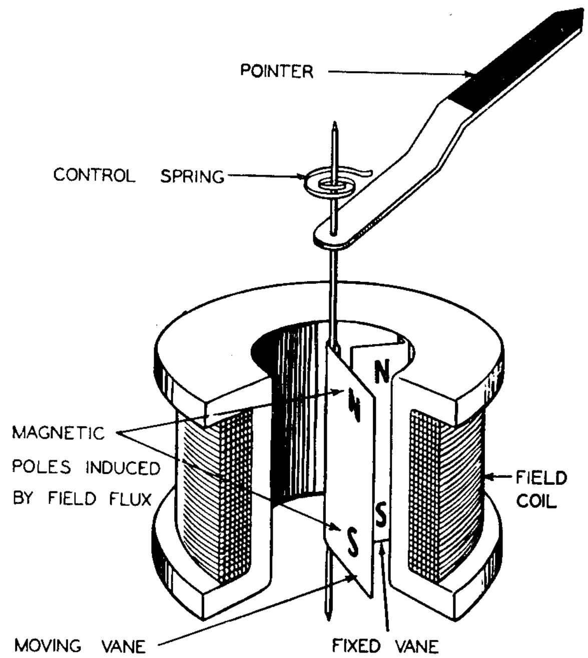


Figure 2-5. Meter Mechanism—Moving-Iron-Vane (Repulsion) Type

mon to both. However, instead of the moving coil used in the dynamometer type of mechanism, iron vanes (or a vane) are employed. Refer to figure 2-5.

(*a*) MAGNETIC PRINCIPLES. — The iron vanes (or a vane) may operate on either of two magnetic principles—attraction-iron or repulsion-iron, or in some instruments on a combination of both, as described in the following paragraphs.

1. ATTRACTION-IRON PRINCIPLE. —The meter mechanism based on this principle consists of a fixed field coil which encloses a movable iron vane affixed to a pointer. When the stationary field coil is energized, the iron vane, which is mounted on bearings, rotates, subject to the restraint of the torque springs, and seeks the position that coincides with the greatest flux density. Since the torque springs oppose the rotation, a balancing of forces results, which permits calibration of the instrument as a measuring device. When alternating current is applied to this mechanism, no rectification is necessary, because the polarity of the iron vane reverses simultaneously with the current reversals occurring in the stationary field coil; therefore, the iron vane is rotated in only one direction, and the extent of the rotation is determined solely by the flux density of the field. This particular form of meter mechanism, based on the attraction-iron principle, is well adapted for general use where high torque (as in recording instruments) is required, but an offsetting disadvantage is that the scale distribution is inherently non-linear.

2. REPULSION-IRON PRINCIPLE.—A variation of the type of mechanism described in the preceding paragraph employs the repulsion-iron principle. A fixed iron vane, the flat surface of which is placed parallel to the flat surface of the moving iron vane, is added. When the magnetic field produced by the stationary coil passes through these vanes, the movable vane is deflected, because both vanes acquire instantaneous identical polarities so that they act to repel each other. The force of repulsion increases as the current in the stationary coil increases. Damping is usually accomplished by means of a light aluminum vane, which moves (with the pointer) in a circular damping chamber so that the friction of the enclosed air opposes violent motions of the pointer. The shape of the iron vanes can be designed to produce a relatively uniform, and a better distributed scale than that of the attraction-iron type; this feature improves readability, making this type of mechanism well suited for use on indicating instruments. Repulsion-iron type meters have an advantage of high overload capacity, since if current of several times normal is applied, the repulsion vanes become magnetically saturated, and the force on the moving system is thus limited to a safe value.

3. COMBINATION. — It is also possible to combine the two principles, attraction and repulsion, to achieve a wider range of pointer movement than would otherwise be possible. Since stationary coil, moving-iron mechanisms provide the simplest and least expensive means of measuring alternating current and voltage, they are utilized in practically all a-c ammeters and voltmeters where circuit conditions permit a fairly heavy instrument-loading effect.

(*b*) APPLICATIONS. — The basic stationary coil, moving-iron meter mechanism and any of its variations are readily adaptable to the measurement of current or voltage. In ammeter applications relatively high currents can be measured without the aid of current shunts, because the stationary coil can be constructed of a few turns of heavy wire. When the mechanism is used as a voltmeter, fairly high voltages can be measured without a voltage multiplying resistor if the stationary coil is composed of many turns of fine wire, which provides sufficient resistance to limit the meter current to a safe value.

2-3. BASIC MEASUREMENTS.

George Simon Ohm, by defining electromotive force (volt) and resistance (ohm) in terms of current flow (ampere), standardized these units and provided the practical basis, "Ohm's law" for modern electrical circuitry.

An electrical circuit in its simplest form consists of a source of electromotive force (voltage) and a continuous conducting path (resistance) through which a current (amperes) flows. The direction of the current (electron flow) in the external circuit is always from the negative terminal (excess of electrons) to the positive terminal (deficiency of electrons) of the source. This electromotive force may be either direct or alternating. If it is direct, the polarity of the positive and negative terminals remains unchanged and the current flows in one direction only. If the electromotive force is alternating, the polarity of the terminal changes at periodic intervals and the current reverses at the frequency of these intervals. In the discussion to follow, d-c and a-c measurements will be treated separately. Resistance measurements, as made with a field type volt-ohm-milliammeter and a typical electronic ohmmeter, will be dealt with as part of d-c measurements, and practicality rather than precision will be stressed.

a. D-C MEASUREMENTS. — A unidirectional current or voltage may be either steady or pulsating, which may also be ac superimposed on dc. The average value of a d-c waveform, which depends for the most part upon symmetry and wave shape, may vary from 63.6 percent of peak value for a rectified (full-wave) sine wave, to 50 percent of peak value for a triangular wave, and further to 0 percent for a superimposed sine wave. Regardless of whether the dc is steady or pulsating, or ac superimposed upon dc, the measuring device indicates the average value. Refer to paragraph 2-2.*a.*(1) (*d*) *1*.

(1) CURRENT. — Theoretically, a current-measuring device should have an internal resistance of zero ohms, so that it would have no loading effect when introduced into the circuit under test, and would reveal the true value of current flowing in the circuit. Practical considerations, however, limit this internal resistance to a definite ohmic value, which is made up of the paralleled resistances of the shunt and the meter movement. This ohmic value may approach zero when extremely high current flow is measured; however, present day circuit applications do not require direct currents of such enormous amperage. Some practical shunts have resistance values as low as .0003 ohm.

The sensitivity of an ammeter (current necessary to produce full-scale deflection) is the limiting factor which determines the lowest possible accurate reading on a meter. For example, if a meter with a 0–1 milliampere movement is connected into a circuit to measure 5 microamperes, the resulting pointer deflection is such a very small part of the total meter range that its usefulness is nullified.

The accuracy of an ammeter reading depends upon the relative magnitudes of the meter resist-

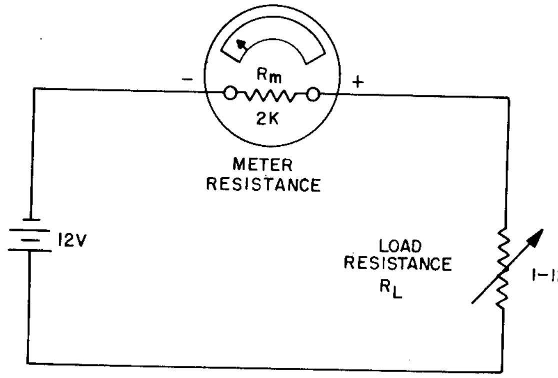


Figure 2-6. Circuit Used to Develop Figure 2-7

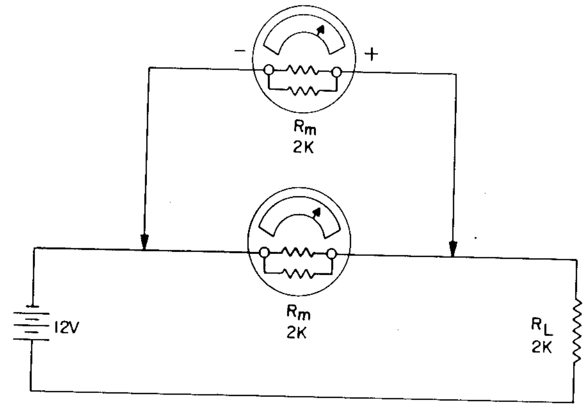


Figure 2-8. Ammeters Connected in Parallel

ance and the circuit load resistance (resistance of the circuit into which the meter is connected). Refer to figures 2-6 and 2-7. When the meter resistance, R_m, equals the circuit load resistance, R_L, the value of the actual circuit current (with the meter removed), as shown by the graph, is twice that of the measured current—representing an error of 50 percent. If the total circuit current is increased (by decreasing R_L), the percentage of error will also increase, and, if the current is increased very much, the percentage of error will increase to such a proportion that the meter indication will be but a small fraction of the actual circuit current. Conversely, if the total circuit current is decreased (by increasing R_L), the percentage of error will also decrease; if the current reduction is continued, the decrease of error will continue, governed by the relationship of meter resistance R_m to circuit load R_L, until the percentage of error becomes so small that for practical measurements it can be disregarded. Thus, for any given circuit load condition, the accuracy of the ammeter reading will be greater if the total meter resistance is much less than the ohmic resistance of the load.

Figure 2-8 illustrates an application of the principle discussed in the preceding paragraph. In this application two ammeters are connected in parallel with each other to measure a current flow which might exceed the scale of one ammeter if used alone. The arithmetical sum of the two meter readings represents the total current flow. Analysis of the circuit in figure 2-8 shows that with both ammeters in the circuit the total circuit current is 4 milliamperes, that with the shunting ammeter removed the total current is 3 milliamperes, and that with both ammeters out of the circuit the total current is 6 milliamperes. Comparing the actual circuit current to the measured current with only one ammeter in the circuit, it is found that the error is 50 percent. Comparing the actual circuit current with the measured current when two ammeters are connected, it is found that the error is only 33⅓ percent. Thus, the paralleled ammeter application, which may be utilized in the field whenever the current to be measured exceeds

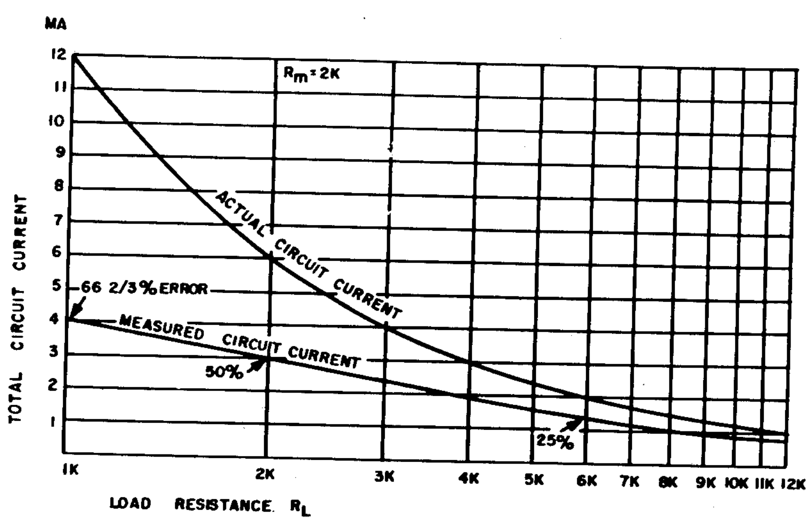


Figure 2-7. Actual Circuit Current vs Measured Circuit Current

the full range of a single ammeter, results in greater accuracy than the use of one ammeter alone.

Figure 2-9 shows the schematic diagram of the ammeter section of a typical volt-ohm-milliammeter. As can be seen in the figure, the meter movement used in this instrument requires 50 microamperes for full-scale deflection. This deflection current is known as the ammeter sensitivity. The shunt used is called the Ayrton shunt or tapped-type, and utilizes shunting resistors R22, R17, R19, R18, and R5 connected with series resistor(s) R11 to provide the following ranges: 0—10 amperes, 0—5000 milliamperes, 0—100 milliamperes, 0—10 milliamperes, and 0—100 microamperes, respectively. It can be seen that the resistance of the tapped-type shunt decreases, bypassing a larger amount of current around the meter movement, as the higher current ranges are used, except on the 100-microampere range, where the current flow is equally divided between the meter and the shunt. When very high values of current are measured, provisions must be made to reduce, or eliminate, switch-contact resistance, which may be appreciably greater than the shunt resistance involved and therefore lead to inaccurate readings. Figure 2-9 shows that on the 10-ampere range, switch contacts for the shunted part of the current have been eliminated by using two separate test receptacles for that range.

Since all meters are current-actuated devices regardless of their scale calibration, it is appropriate to include in this discussion of current-measuring meters the following rules concerning the use of d-c meters in general:

To protect the meter, use the highest range for the initial measurement of a current or voltage of unknown magnitude.

Observe polarity on all direct-current instruments.

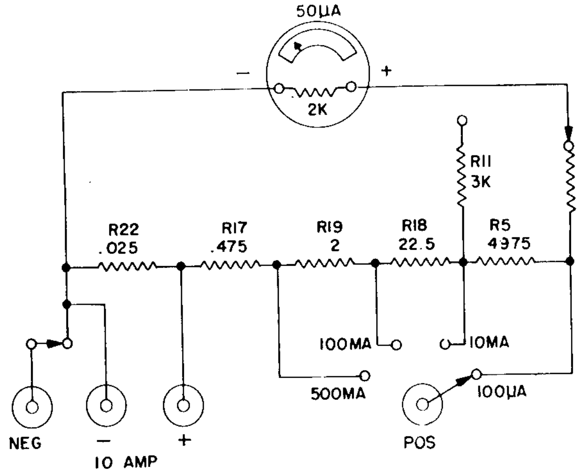


Figure 2-9. Simplified Schematic Diagram of Ammeter Section Taken from Typical Volt-Ohm-Milliammeter

Be cautious when using an ohmmeter to measure resistance in any circuit involving a meter movement. (See CAUTION below.)

Do not drop a meter or subject it to excessive mechanical shock—such treatment may damage the delicate mechanism or cause the permanent magnet to lose some of its magnetism.

CAUTION

Never attempt to measure the internal resistance of a meter movement with an ohmmeter as the movement may be damaged by the relatively high current required for the ohmmeter operation.

(2) VOLTAGE.—Unlike the low-resistance ammeter, a voltmeter should theoretically have an infinite internal resistance so that it would absorb no energy from the circuit under test and would therefore measure the true circuit voltage. In practical meters some circuit effect is unavoidable; however, it is minimized as much as possible by utilizing highly sensitive meter mechanisms, and also, as will be discussed later, by using electron tubes in connection with the meter—as in the electronic voltmeter.

(*a*) VOLT-OHM-MILLIAMMETER (MULTIMETER).—The basic sensitivity of an ammeter is given in terms of the current required to cause full-scale deflection of the pointer. Voltmeter sensitivity is dependent upon this basic sensitivity but is expressed in a different manner. As mentioned previously, a voltmeter, which is connected in parallel with that portion of the circuit across which the voltage is to be measured, should have as high a resistance as practical; hence, to make the expression of sensitivity useful it is expressed as the number of ohms present in the meter circuit for each volt of the meter range, or more simply in ohms per volt. Mathematically it is the quotient found by dividing the current necessary for full-scale deflection into one volt. The sensitivity multiplied by the range in volts quickly gives the value of the total shunting resistance (meter and series multiplying resistor) placed in the circuit under test when the voltmeter is connected for a measurement. For example, the shunting resistance on the 10-volt range of the 50-microampere (20,000-ohms-per-volt) meter shown in figure 2-10 (over-all schematic diagram shown in figure 2-24) is 10 volts time 20,000 ohms per volt, or 200,000 ohms. This fact can be verified by adding the values of series resistors R12 and R10 and the value of the meter resistance (2000 ohms). Stated more simply, a voltmeter is a high-resistance ammeter the voltage drop of which adds in series with the voltage drops across the multiplying resistors to form the total voltage across the circuit under test.

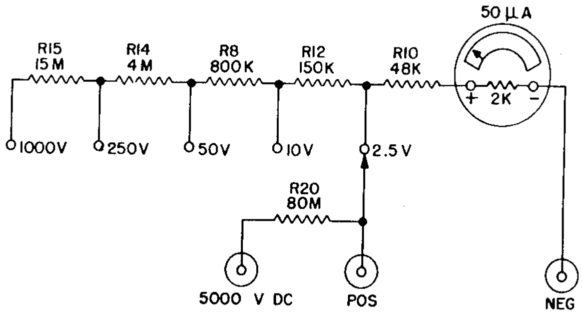


Figure 2-10. Simplified Schematic Diagram of D-C Voltmeter Section Taken from Typical Volt-Ohm-Milliammeter

The accuracy of any measurement taken with a voltmeter depends, for the most part, upon the relationship between the total resistance in the meter circuit and the value of resistance across which the voltage is measured. This fact can be seen from a study of the circuit in figure 2-11 and the graph in figure 2-12, which shows both the actual voltage and the measured voltage, as well as the percentage of error, for various values of load resistance, R_L. In figure 2-12 when load resistance R_L (4K) is twice the meter resistance (2K), the voltage measured is one-half the actual voltage across R_L—an error of 50 percent. If R_L is decreased until R_L equals R_m, the error is 33.3 percent. Proceeding further, if the load resistance is made one-half the meter resistance, the error diminishes to 20 percent. Continuing to increase the ratio between the circuit load and the meter resistance by decreasing R_L further reduces the error, so that for practical purposes the voltmeter error can be tolerated when the voltmeter resistance is ten times greater than the resistance across which the voltage is taken.

Figure 2-13 shows a practical application of the principle discussed in the paragraph above. In this application two voltmeters are connected in series across the voltage to be measured to obtain a higher-voltage range than that provided by one instrument alone, and at the same time to provide a more accurate reading. Analysis of the circuit in figure 2-13, which is similar to the one in figure 2-11, shows that with one voltmeter connected R_L equals R_m and the error is 33.3 percent. Addition of the second voltmeter is in effect the same as decreasing R_L to one-half its former value. Reference to figure 2-12 shows that this condition results in an error of 20 percent. It follows then that the use of two voltmeters in series is practical for field application, because it extends the usable ranges of available meters, and at the same time provides greater accuracy. If necessary, several similar voltmeters can be connected in this manner; the total voltage drop is the sum of the individual meter indications.

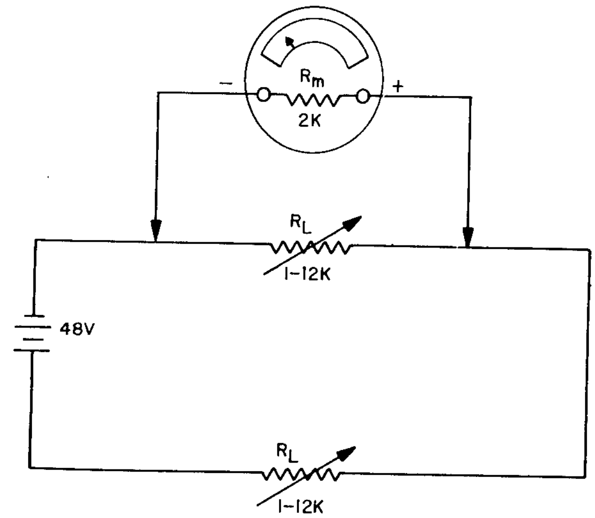


Figure 2-11. Circuit Used to Develop Figure 2-12

(*b*) ELECTRONIC VOLTMETER. — From the discussion concerning the volt-ohm-milliammeter it should now be evident that the in-

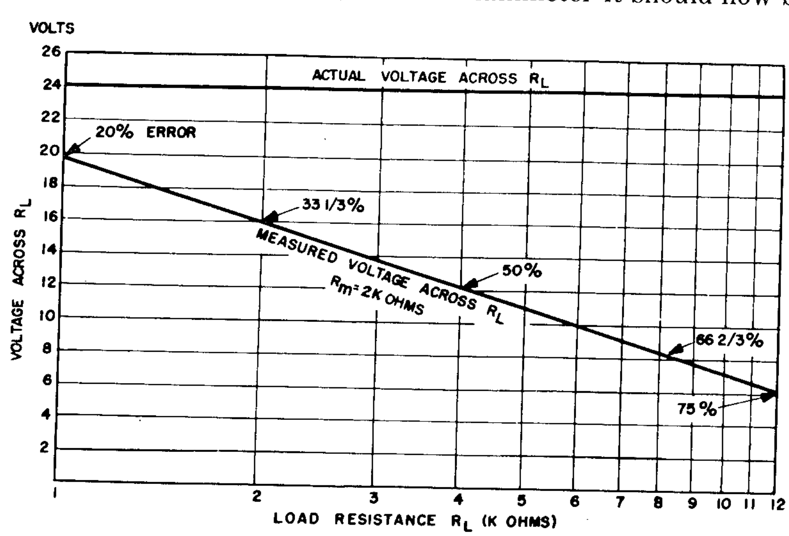


Figure 2-12. Actual Voltage vs Measured Voltage

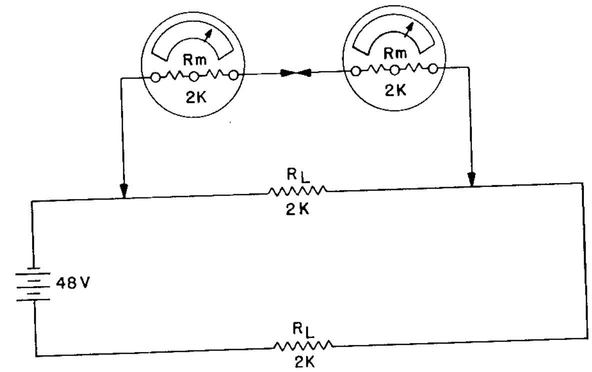


Figure 2-13. Voltmeters Connected in Series

troduction of any meter into a circuit will cause energy to be taken from the circuit, and that the amount of the energy taken depends, for the most part, upon the meter sensitivity. Reference to figures 2-11 and 2-12 shows that at the 50-percent error point the power (E^2/R) taken from the circuit is 72 milliwatts. The extraction of energy necessary to operate this type of meter cannot be avoided and in some circuits can be tolerated; however, in extremely sensitive circuits, such as oscillator grids, automatic volume control, automatic frequency control, discriminator output, etc., disruption of normal circuit operation will occur, resulting usually in no indication being obtained. Primarily for this reason an electron tube is often utilized in conjunction with a meter to provide a very high shunting resistance across the circuit under test and to increase the relative sensitivity currentwise. The current and voltage gains of an electronic voltmeter will be discussed by considering an example. The ordinary 0-1 ma. meter has a somewhat low resistance (approximately 50 ohms) and therefore requires 50 millivolts for full-scale deflection. If this meter is connected to a source of 50 millivolts of low internal resistance, it will read full scale. Consider, theoretically, the same meter connected into the plate circuit of a triode (6J5) tube so that it does not read normal plate current, but only responds to changes in the plate current. Assume that when a 50-millivolt source is connected in the grid circuit, the meter shows a deflection of .05 milliampere, or 1/20 of full scale. Then the voltage drop across the meter is .05 milliampere multiplied by 50 ohms, or 2.5 millivolts, which is much less than the input. The voltage gain is less than unity or .05. From basic amplifier study it should be recalled that for high voltage gain it is necessary to use a high resistance in the plate circuit. The formula for voltage gain is:

$$\text{Voltage gain} = \frac{\text{mu X load R}}{\text{dynamic plate R} + \text{load R}}$$

The milliameter considered in this problem could not be used to measure the voltage developed across a high value of plate load resistor, because it would effectively (shunt) reduce the load resistance to 50 ohms and cause the voltage amplification to be very low. Evidently, voltagewise a net loss in sensitivity has resulted through the use of the amplifier in conjunction with the meter.

Considering the sensitivity currentwise, it is found that very high current gain can be realized. If the grid resistor in the above example is 10 megohms and the grid current is negligible, calculation from Ohm's law shows that current from the voltage source (50 mv) is .005 microampere, and the current gain is 10,000. The energy taken from the circuit (I^2R) is .00025 microwatt, which is 200 times smaller than the amount of energy (.05 microwatt) taken from the circuit by the 0—1 ma meter connected directly across the 50-mv source. With well-designed tubes, grid resistance can be maintained very high and coupled with high transconductance (Gm) extremely high current gain, which is proportional to the resistance in the grid circuit, can be effected. It is seen then that a single-tube d-c electronic voltmeter produces extremely high current amplification, but less than unity voltage amplification, and that the important characteristics are grid resistance and tube transconductance. Electronic voltmeters are very practical where no energy or only extremely small amounts of energy can be taken from the circuit under test.

1. BASIC ANALYSIS.—The electronic voltmeter, which was conceived and designed to perform functions beyond the capabilities of other measuring devices, possesses many advantages. The ability to measure voltages in sensitive electronic circuits, where the total energy available in the circuit under test may be only a few microwatts, without disturbing or causing such circuits to become inoperative is of prime importance. Figure 2-14 shows a block diagram of a typical electronic voltmeter and figure 2-25 shows the over-all schematic. In the following discussion

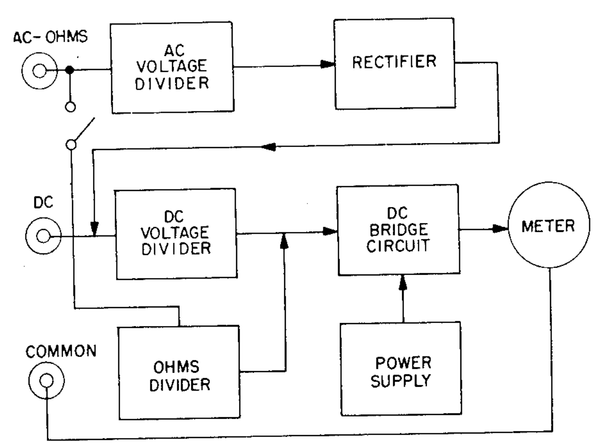


Figure 2-14. Block Diagram of Typical Electronic Voltmeter

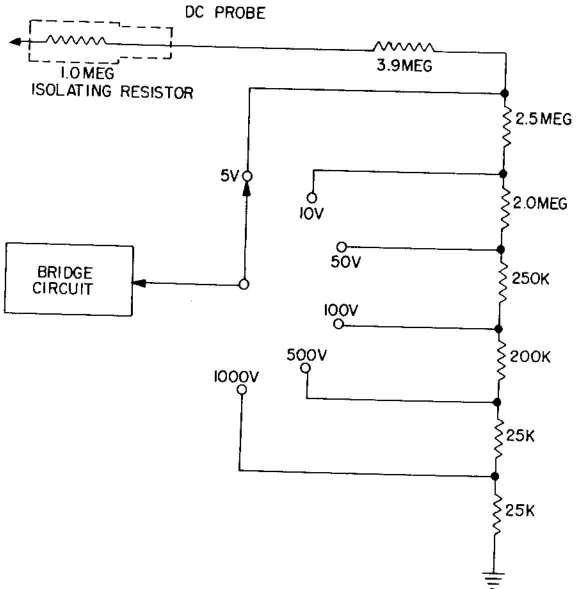


Figure 2-15. D-C Voltage Divider

concerning d-c voltage measurements, the blocks labeled d-c voltage divider and d-c bridge circuit will be included because it is by means of these combined circuits that the input impedance and the sensitivity of the voltmeter are maintained very high.

2. D-C VOLTAGE DIVIDER.—The d-c voltage divider, as shown in figure 2-15, provides a very high input impedance (9.9 megohms) and at the same time drops the voltage under test to a low value at the grid (2.52 volts is necessary to produce full-scale deflection of the meter in the bridge circuit). As the voltage range is extended more resistors are placed in series with the d-c probe and fewer resistors are connected from grid to ground, so as to maintain approximately the same grid voltage input to the bridge circuit. The d-c probe includes an isolating resistor (1 megohm), which serves to minimize capacitive loading of the measured circuit. Very low capacitive loading is important if the circuit contains r-f voltages, and is of particular importance in the case of resonant circuits, which might otherwise be thrown out of alignment for the duration of the measurement.

3. D-C BRIDGE CIRCUIT. — If an electronic voltmeter employing a single triode tube, as discussed in paragraph 2-3.*a.*(2) (*b*), were used to measure voltages of different polarities, the scale would have to be calibrated on both sides of a center-scale zero to provide for plate current variations with grid polarity changes, unless an alternate provision for reversing the meter connections was used. Zero center calibration decreases the effective meter scale length and consequently reduces the measuring accuracy (readability). However, in testing a-c or a-f-c control circuits, use of a zero center scale voltmeter is very convenient; hence, some voltmeters with zero on the left side of the scale are designed so that the pointer can be set to center scale for such measurements.

By using a two-tube bridge circuit, as shown in figure 2-16, and by switching the d-c probe to either grid of these tubes, it is possible to obtain an up-scale meter deflection for both polarities of the probe voltage. Analysis of the circuit of figure 2-16 shows that a point can be reached on the zero adjust potentiometer (0—15K) where the plate currents of the triodes are equal. At this

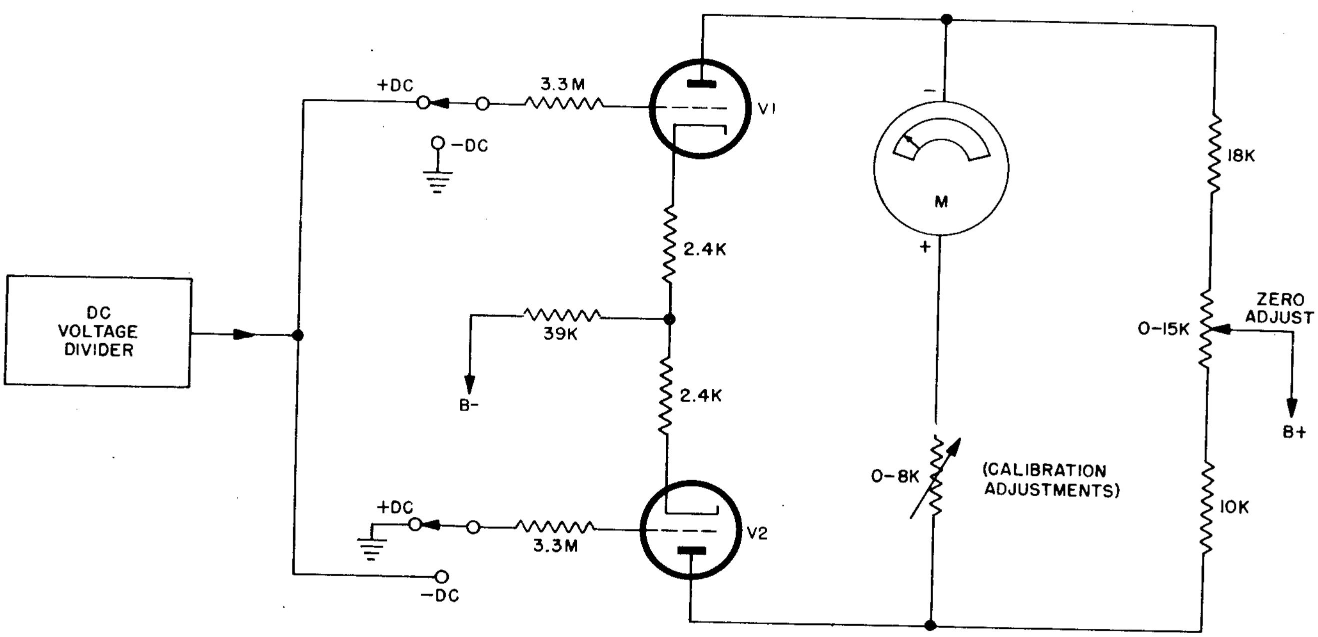


Figure 2-16. D-C Bridge Circuit

point the plate voltages on both tubes are equal, and the bias developed across the cathode resistors provides class A operation for the tubes. To minimize undesirable grid current flow, the tubes are operated considerably below their normal plate and heater potential ratings, and a large (3.3 megohms) value of series resistance is used in the grid circuit to avoid any positive excursions of the grid, which could quickly build up and result in severe damage to the tube. The 3.3 megohm series resistor also limits the percentage change of resistance from grid to ground as seen by the grid when different voltage ranges are selected.

If a positive d-c potential is applied, by means of the voltage divider and d-c probe, to the grid of V1 through the polarity switch, it can be seen in figure 2-16 that with the grid of V2 at ground potential more plate current will flow through V1, decreasing the plate voltage through that tube. This plate voltage unbalance then causes current to flow through the meter circuit with the polarity indicated. With the polarity switch thrown to minus (−) D-C position, the grid of V1 is now at ground potential and with a negative d-c potential applied to the grid of V2, plate current through this tube now decreases and the plate voltage increases. This plate voltage unbalance, which is in the same direction as before, causes meter current to flow with the same polarity as that when the d-c potential under test was positive.

WARNING

Do not reverse the test leads when measuring high voltages of different polarities. Use POLARITY REVERSE switch on the electronic voltmeter. Contact between the voltmeter case and ground may cause severe shock, if the above caution is not observed.

From the point of view of accuracy, the bridge-circuit method of obtaining up-scale deflection with different polarities of probe voltage is most desirable, because the operation of the d-c bridge is identical for a given input voltage regardless of polarity. The linear portion of either characteristic curve is utilized in that the grid of one tube always swings negative and the grid of the other tube always swings positive, with ground as reference, regardless of the polarity of the probe voltage.

(*c*) INPUT RESISTANCE — ELECTRONIC VS. NON-ELECTRONIC VOLTMETERS.—In sensitive circuits the input resistance of any measuring device is an important factor which could cause circuit disturbance or render the circuit completely inoperative. The input resistance also affects the accuracy of any measurement, as explained in paragraph 2-3.*a.*(2) (*a*). Table 2-1 shows the relative circuit loading effect of a non-electronic voltmeter as compared with that of an electronic voltmeter (VTVM).

TABLE 2-1. CIRCUIT LOADING EFFECT—VTVM VS NON-ELECTRONIC VOLTMETER

RANGE	INPUT RESISTANCE		CIRCUIT LOADING EFFECT
	VTVM	Non-Elec.*	
5V	10 meg	0.1 meg	Non-Electronic Voltmeter 100 times that of VTVM
10V	10 meg	0.2 meg	Non-Electronic Voltmeter 50 times that of VTVM
50V	10 meg	1 meg	Non-Electronic Voltmeter 10 times that of VTVM
100V	10 meg	2 meg	Non-Electronic Voltmeter 5 times that of VTVM
500V	10 meg	10 meg	Non-Electronic Voltmeter same as VTVM
1000V	10 meg	20 meg	Non-Electronic Voltmeter one-half that of VTVM

*Non-Electronic Voltmeters (20,000 ohms-per-volt)

(3) D-C RESISTANCE.—Resistance is that quality a material possesses because of its composition (atom structure), cross sectional area, and length — which retards or impedes a flow of electrons through it. Since the current in any series circuit is inversely proportional to the total circuit resistance, it is possible to calibrate a meter to read in terms of resistance. The use of suitable shunts makes such an instrument practical. Refer to paragraph 2-2.*a.*(1) (*c*). The discussion to follow will consider the measurement of resistance with a typical non-electronic ohmmeter and an electronic ohmmeter where absolute accuracy is not necessary, but rather portability, convenience, and speed are of importance. Since the range of measurements of any typical ohmmeter may vary from zero to infinity ohms, some points on the scale besides the end points are needed to indicate the usable range of the ohmmeter. The most practical point to use is the center scale resistance reading. If this point is known then the maximum practical reading is ten times the center scale reading and the minimum practical reading is one-tenth of the reading. However, some manufacturers do not adhere to these limits when calibrating meters, and designate ranges by what they consider to be the maximum range reading, which means very little unless the center scale reading is known. If the maximum usable reading is considered to be 100 times the center scale reading, the higher readings will be useless. The center scale reading can be readily found by examining the meter face, and from it the maximum and mini-

mum practical limits for any range can easily be determined.

(*a*) VOLT-OHM-MILLIAMMETER. — In current and voltage measurements the energy required to deflect the meter is derived from the circuit under test. An ohmmeter, which measures the opposition to current flow, must have its own source of energy (usually a battery). Therefore, when a resistance measurement is taken, the circuit involved must be completely de-energized, and any components likely to be damaged by the battery in the ohmmeter (such as low-filament current tubes and meters) must be removed from the circuit.

CAUTION

Never attempt to measure the internal resistance of a meter movement with an ohmmeter as the movement may be damaged by the relatively high current required for the ohmmeter operation.

Figure 2-17 shows a simple ohmmeter section taken from a typical volt-ohm-milliammeter. It is a shunted series type of ohmmeter. When the range switch is turned to the positions marked R x 1, R x 100, and R x 10,000, the proper series and shunt resistors and batteries are connected into the circuit, so that with the test leads shorted the meter reads full scale.

Examination of the meter face discloses the center scale reading to be 30 ohms. With this information and knowing the resistance multipliers, it can be calculated that the lowest practical resistance reading on this ohmmeter is 3.0 ohms; the highest, 3.0 megohms.

CAUTION

Do not leave the range selector switch in a resistance measurement position when the meter is not in use because the test leads may become shorted and run down the internal battery. It is also possible that the instrument may be connected across a voltage accidentally and thereby cause damage to the meter.

(*b*) ELECTRONIC OHMMETER. — For the measurement of resistance with an electronic ohmmeter, series resistors (10 megohms total) connected by means of a battery (3 volts) to ground are switched into the grid circuit of V1 as the successive ranges (R x 1 through R x 1 megohm) are selected. Refer to figures 2-18 and 2-16. With the range switch set to R x 1 and the test prods open, a voltage of approximately +3 volts is applied to the grid of V1 (V2 is grounded) and produces full-scale meter deflection on the +5V DC range, as shown on the electronic voltmeter over-all schematic diagram in figure 2-25. At this time the pointer is set to infinity ohms by means of the 7K OHMS ADJUST potentiometer. Shorting of the prods places the grid of V1 at ground potential, and the meter now reads zero ohms. From the schematic diagram in figure 2-18 (block diagram shown in figure 2-14), it can be seen that, with the prods still shorted and using the R x 1 range, the battery delivers 300 milliamperes through the 9.5-ohm resistor and the meter reads zero. If a 9.5-ohm resistor is now inserted between the prods, the meter should read midscale, showing that the center

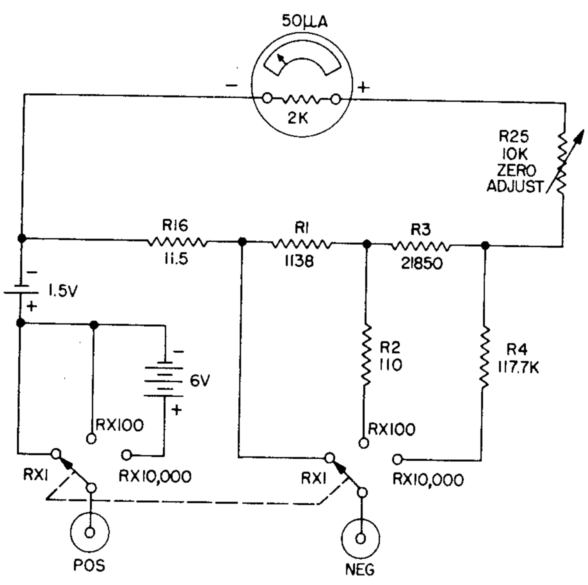


Figure 2-17. Simplified Schematic Diagram of Ohmmeter Section Taken from Typical Volt-Ohm-Milliammeter

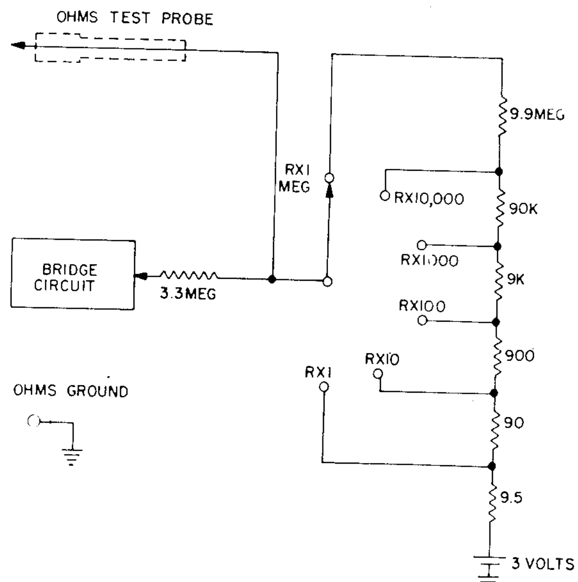


Figure 2-18. Simplified Schematic Diagram of Ohmmeter Section Taken from Typical Electronic Voltmeter

scale resistance reading is approximately 9 ohms or multiples thereof for the other ranges.

Prolonged use of the low ohms range (R x 1) should be avoided, if possible, because it is on this range that the battery load is heaviest. When making measurements below 2 ohms, in order to cancel the lead resistance error, short the test prods together and reset the ZERO ADJUST control so that the pointer reads exactly zero. This new setting will be slightly different from the original setting because of the test-lead resistance. When the measurement has been completed, the ZERO ADJUST control should be reset as would normally be done on any voltage range. When high resistances are measured, the fingers should be kept away from the test probe. This will eliminate possible error due to leakage and stray pick up. This is especially important on the R x 10,000 and the R x 1 megohm ranges.

It is possible to extend the range of this ohmmeter to measure resistances higher than that covered by the R x 1 megohm range, if an external voltage supply is utilized. This application is especially useful for the measurement of insulation resistance of paper and mica capacitors, which for the smaller capacities is usually above 1000 megohms. The voltage supply may range in output from 20 to 500 volts. Higher-voltage outputs make it possible to measure higher resistances. Make the connections as shown in figure 2-19 and note the d-c voltage readings at points A and B, using the most convenient range for each measurement. If the voltage at point B is too small to be accurately readable, increase the output of the power supply until a readable voltage is obtained. The unknown resistance, R_x in megohms, can be found from the following formula:

$$R_x = \frac{9.9 \text{ x (voltage at A)} - \text{(voltage at B)}}{\text{Voltage at B}}$$

This formula may be derived from the proportion existing between the voltages across R_x and the 9.9 megohm voltage divider, and their respective resistances.

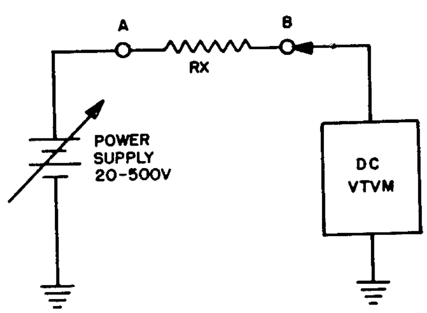


Figure 2-19. Circuit for Resistance Measurements Above 1000 Megohms

(*c*) ELECTRONIC VS NON-ELECTRONIC OHMMETERS. — As may be seen from the schematic diagram shown in figure 2-18, on the R x 1 range the 9.5-ohm resistor provides center scale resistance reading for the electronic voltmeter and at the same time, with the test prods shorted, causes the battery to supply 300 ma. to the circuit. It is impractical to decrease the value of the 9.5-ohm resistor, because a lower value of resistor at this point would cause a decrease in the practical limits of the highest range (R x 1 MEG) and also would load the 3-volt battery to such an extent that its terminal voltage would drop (across its own internal resistance) to a value insufficient (on grid of V1) to cause full-scale deflection of the meter. However, at this point it should be stressed that, whether an electronic or a non-electronic ohmmeter is involved, it is decidedly impractical to measure extremely low values of resistance with an ohmmeter type of test equipment. There are other test equipments that provide more precise low-resistance readings.

Comparison of figure 2-18 with figure 2-17 shows that the electronic ohmmeter can reach a higher high range with a lower internal voltage source than the non-electronic because the energy necessary to deflect the meter comes from the electronic voltmeter power supply rather than from the internal voltage source, as in the non-electronic. It is seen then that, because the current gain of an electron tube is utilized, the electronic voltmeter invariably provides a higher-resistance range than the non-electronic, which is limited in extending its highest range by the practical value of its internal source voltage and also by the sensitivity of the meter mechanism.

b. A-C MEASUREMENTS. — An alternating current (or voltage) is a succession of surges, increasing in one direction from zero to a maximum point and decreasing back to zero, and then repeating the process in the opposite direction. Two surges, one called positive current and the other negative current, form one cycle of alternating current. It is evident from the alternating nature of this current (or voltage) that the surges can assume various shapes (waveforms), and that the alternations can take place in a short or long time (frequency). If these surges are to be described electrically, the amplitude of some specified point in the cycle must be known (either current or voltage).

The sine wave is considered to be the basic waveform—and from it more complex waveforms are developed by adding in-phase (or out-of-phase) even (or odd) harmonics of the fundamental waveform to produce, for example, square or sawtooth waveforms. A pure sine wave is symmetrical and free from harmonics. For pur-

poses of measurement, various values—peak, effective (rms), and average—were established. The peak value, as the name implies, is the highest value that the sine wave attains; the effective value (root mean square) is 70.7 percent of the peak value; and the average value (full-wave rectified) is 63.6 percent of the peak value. The effective value of an alternating current is equal to the value of direct current that will produce the same average power dissipation (or heating effect) in a resistance as the alternating current.

The frequencies of alternating currents vary widely. For purposes of measurement the spectrum will be divided into the following: power (commercial) frequencies, audio frequencies, and radio frequencies.

(1) POWER (COMMERCIAL) FREQUENCIES.—In this range of frequencies (up to 3000 cps) great amounts of energy, as a rule, are transferred from generator to load, so that the measuring instrument loading effect on the circuit, although great in some cases, can easily be tolerated. The selection of current and voltage measuring instruments for a given application depends not only upon the choice of the proper mechanism but also upon the conditions of the application, such as recording or indicating, portable or stationary, sensitive (laboratory) or rugged (shipboard).

In the power zone of a-c frequencies the moving-iron mechanism is not frequently used for direct measurement of current and voltage, because the use of a heavy, inefficient multiplier is required, and the current drain is high, which results in the development of excessive heat within the meter case. Lightweight transformers which are used to change the line voltage or current to a workable value, are commonly found in current and voltage metering applications in this range of frequencies. No difficulty is ordinarily encountered in the use of a potential transformer except that the correct polarity must be observed. On the other hand, a current transformer can be dangerous if the following precaution is not observed:

WARNING

The secondary, or meter side, of the transformer should be short-circuited when the meter is removed.

This is necessary to prevent the voltage of the transformer secondary from building up to a dangerous potential. If the secondary is left on open circuit, a high voltage will exist across it when a heavy current flows through the primary winding, because the same turns ratio that reduces the current also increases the voltage. Since the current-transformer secondary is designed for use across a low-resistance ammeter movement, its insulation can be easily punctured if the above warning is not obeyed. Portable current transformers are customarily provided with a built-in shorting switch, which should be kept closed except when the ammeter is being read.

(2) AUDIO FREQUENCIES. — Audio frequencies, which are so named because the human ear (to varying degrees) responds to them when they are converted to air disturbances, range from 16 to 20,000 cycles per second. No single type of instrument permits all a-c measurements as readily as the D'Arsonval type meter lends itself to d-c measurements. As a result of the inability of the D'Arsonval type of movement to operate directly on ac, auxiliaries (rectifier or thermal converter) must be used with this instrument, or an electronic voltmeter with a diode rectifier or other types of movements suitable for direct operation on ac must be employed.

(*a*) CURRENT. — For the measurement of audio-frequency current, a thermal converter (see figure 2-20) is utilized in conjunction with a d-c meter movement; the test equipment is called a thermocouple ammeter. For the description and operation of this ammeter, refer to paragraph 2-2.*a*.(1) (*d*)*2*.

Another a-f (or r-f) current measuring device is the hot-wire ammeter. Figure 2-21 shows the basic operation of this type of meter. The heat effect of the current under measurement is used, but in a different manner than in the thermocouple ammeter. In the latter meter advantage is taken of the small d-c potential generated by the heating of two dissimilar metals to operate a meter movement. In the hot-wire ammeter the

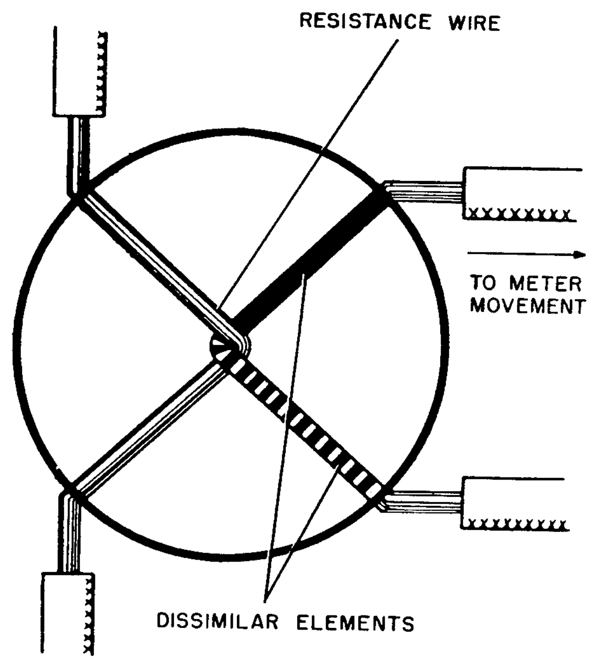


Figure 2-20. Thermal Converter

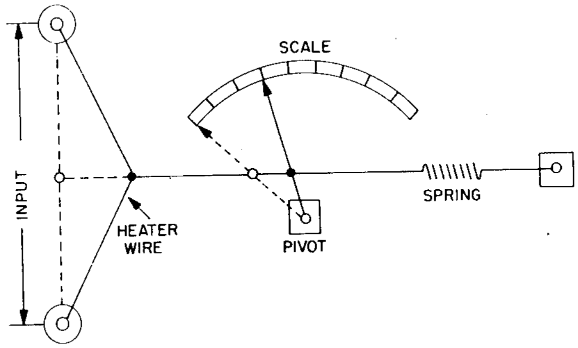


Figure 2-21. ***Basic Hot-Wire Ammeter***

heating effect expands the heater wire, and the meter indication is the result of a mechanical force, which is produced by the spring acting on the expanded heater wire.

(*b*) VOLTAGE. — For the measurement of audio-frequency voltages the permanent magnet-moving coil type meter movement in conjunction with a copper oxide rectifier is commonly used; also an electronic voltmeter employing a diode rectifier may be used.

1. VOLT-OHM-MILLIAMMETER.— Figure 2-22 shows the a-c voltmeter section of a typical non-electronic multimeter. Although two copper oxide rectifier units are used, the output delivered to the meter is half-wave rectified. One rectifier unit supplies its half-wave output to the meter, and the other bypasses the meter on the alternate half-cycles of the a-c input so that the front-to-back ratio (forward-to-reverse resistance) of the meter circuit can be maintained when multiplying resistors are switched into the circuit. The front-to-back ratio of a good rectifier unit is approximately 1000 to 1. If this rectifier unit were the only component in series with the meter, the current ratio would be approximately 1000 to 1. Now assume that a 10K resistor is placed in series with the meter and a single rectifier. The front-to-back ratio of the circuit as a whole would be approximately 10,000 to 11,000, or approximately 1 to 1. Hence, the amount of conduction would be practically the same in both directions, and there would be no resultant up-scale deflection of the meter. If the second rectifier unit is added to the circuit, the reverse current will flow around (instead of through) the meter, and the front-to-back ratio of meter circuit will be maintained very close to the original ratio (1000 to 1). It is seen then that without the second rectifier unit the meter would be inoperative when voltage multiplying resistors are switched into the circuit as various voltage ranges are selected. Shunt resistor R24 and series resistor R23 are precision wound, and are calibrated with the rectifier unit with which they are used. The resulting sensitivity on the a-c range is 1000 ohms per volt.

A simple modification—the addition of a blocking capacitor (.1 microfarad) from the a-c voltmeter section to an output receptacle—converts this meter into an a-f output meter.

2. ELECTRONIC VOLTMETER. — A d-c electronic voltmeter may be used to measure a-c voltages by employing a rectifier (diode) and the necessary switches with a voltage divider. Figure 2-23 shows a simplified schematic diagram of an a-c voltmeter section of a typical electronic voltmeter, and figure 2-14 shows a block diagram

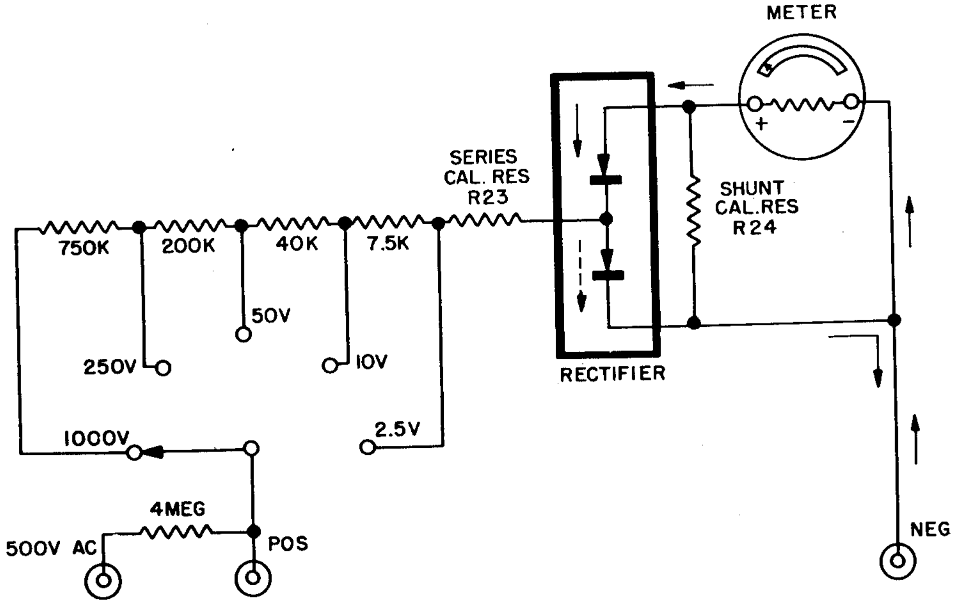


Figure 2-22. ***Simplified Schematic Diagram of A-C Voltmeter Section Taken from Typical Non-Electronic Multimeter***

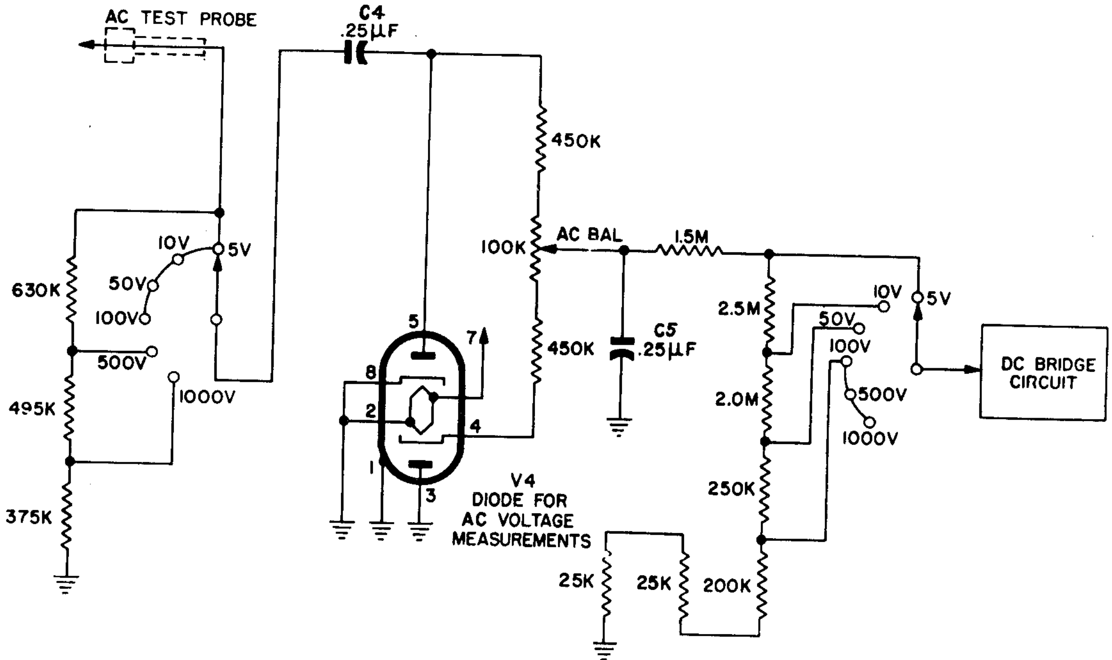


Figure 2-23. ***Simplified Schematic Diagram of A-C Voltmeter Section Taken from Typical Electronic Voltmeter***

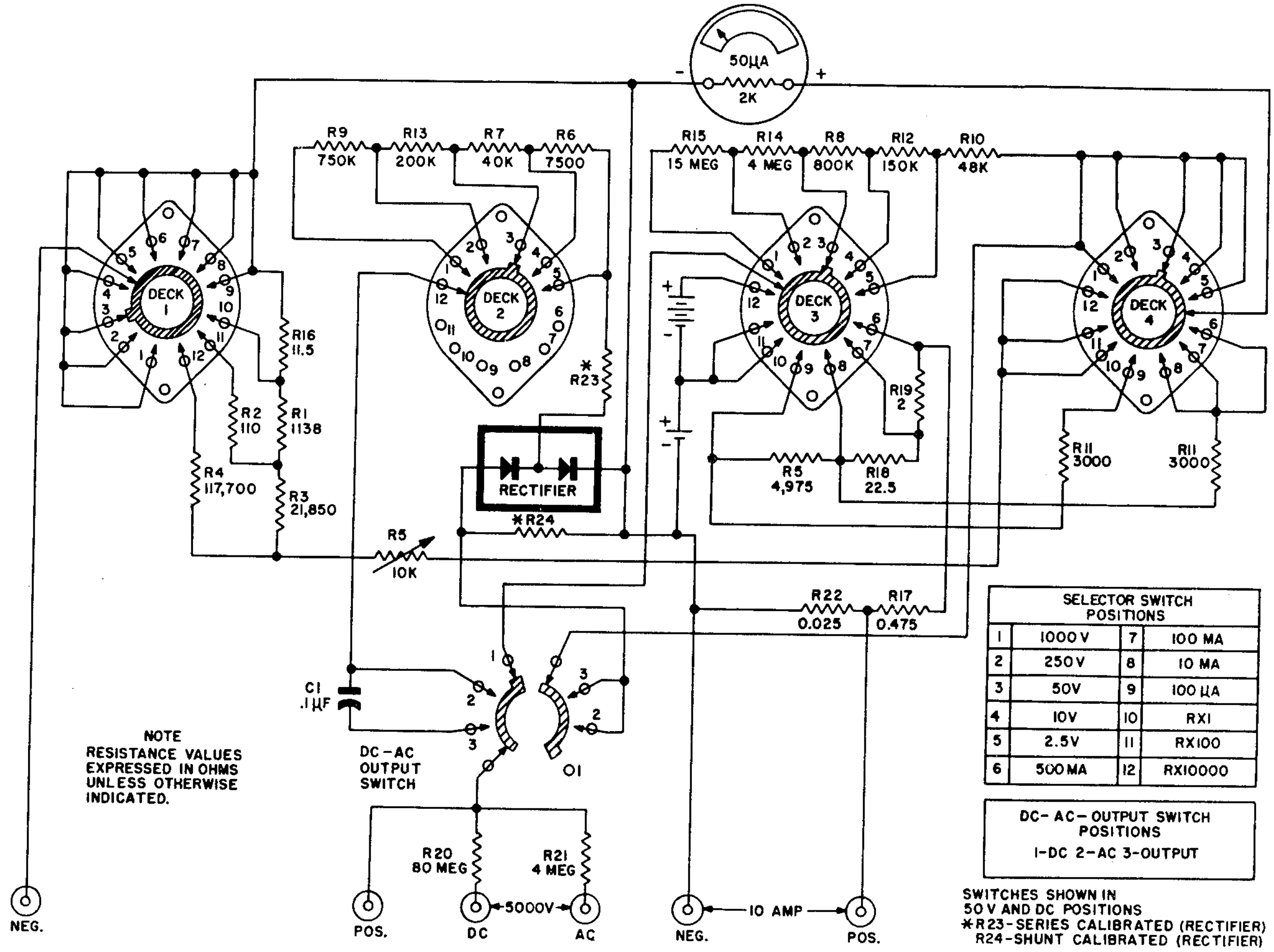


Figure 2-24. ***Over-all Schematic Diagram of a Typical Volt-Ohm-Milliammeter***

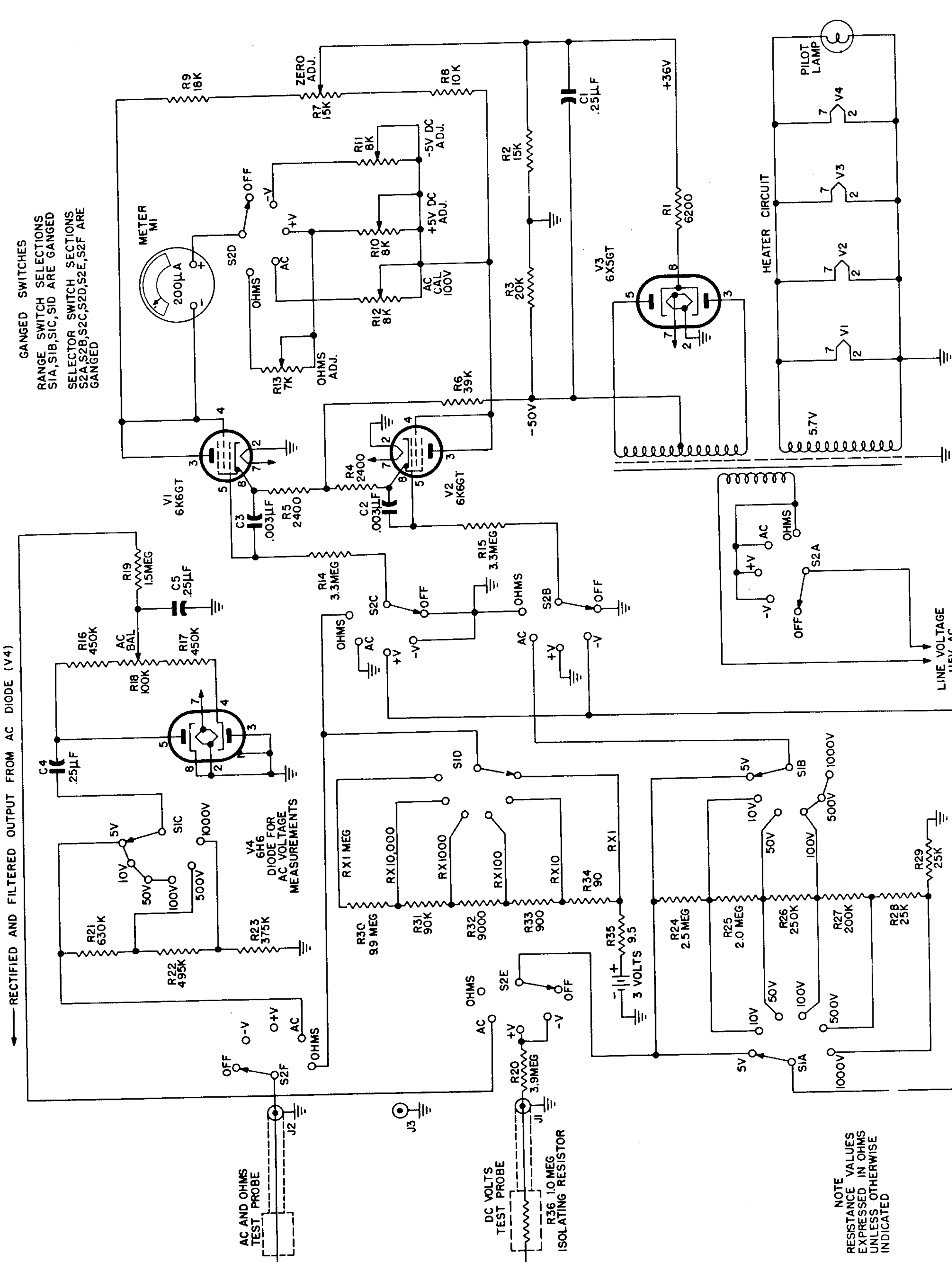


Figure 2-25. Over-all Schematic Diagram of a Typical Electronic Voltmeter

of the circuit. Figure 2-25 is an over-all schematic diagram for a typical electronic voltmeter. The voltage under test is applied to the diode plate by means of d-c blocking capacitor C4, and the plate is referenced to ground through the voltage divider. After rectification the negative d-c voltage is filtered by C5 (.25 microfarad) and is fed by means of the d-c voltage divider to the grid of V2. Refer to paragraph 2-3.*a.*(2) (*b*)*3.* for an explanation of the operation of the d-c bridge circuit when negative potentials are applied to the grid of V2.

The maximum allowable plate voltage on diode V4 is 150 volts (rms). In order to protect this tube when the voltage under test exceeds 100 volts (rms), the a-c voltage divider is used to drop the voltage to a level that supplies V2 with a usable grid voltage and at the same time does not exceed the maximum allowable plate voltage.

(3) RADIO FREQUENCIES. — In practical use, radio frequencies are considered to range from 10,000 cycles to 30,000 megacycles. However, radio frequencies extending above 1,000,000 megacycles have been measured and are at present being used experimentally. In the range of practical radio frequencies power measurements are considered of the greatest importance; however, for certain applications r-f current and voltage measurements are sometimes required to be taken.

(*a*) CURRENT. — For r-f current measurements the applicable instruments have been discussed under audio frequencies. Refer to paragraph 2-3.*b.*(2) (*a*). (R-F power measurement will be discussed in paragraph 2-6.)

(*b*) VOLTAGE.—It is possible to measure a-f voltages (up to 20,000 cycles) with a volt-ohm-milliammeter. Above this point, however, the inherent capacitive effect of the copper oxide rectifier causes the amplitude of the frequency response curve to decrease, making voltage readings inaccurate. By using a diode rectifier (as in the electronic voltmeter) instead of a copper oxide rectifier, it is possible to extend the frequency response curve to a point (approximately 100,000 cycles) at which the resistance and capacitance of the test leads prevent a further increase in the response curve and again introduce an appreciable error. If a probe containing a rectifier is used, the error introduced by the resistive and capacitive effect of the long test leads is greatly reduced, and consequently r-f voltages of a much higher frequency can be read accurately.

A common type of a-c probe uses a diode rectifier tube and generally a blocking capacitor and isolating resistor. In addition to the above, the contact end of the probe prod is provided with a short ground connection—a circumferential ring (clip-on contact)—to eliminate stray circuit capacitance (resonant loops). The diode action, in conjunction with the charging of the blocking capacitor, produces a peak rectifier output. After the a-c input has been applied for several cycles, the diode conducts only during a sufficient portion of each cycle to supply the small d-c current demanded by the voltage divider in the voltmeter. A typical electronic voltmeter is usually calibrated to read the effective (rms) a-c value, which is less than the peak value. The instrument is therefore calibrated in terms of the r-m-s value of a pure sine wave, which has a peak value of 1.414 times its effective value.

With the diode probe it is possible to read voltages accurately up to 100 megacycles; at this point the limiting factor is the inherent distributed inductance and capacitance between the rectifier tube elements and the point of measurement, with maximum error occurring at resonance. Recent development of germanium diode rectifiers, which are efficient at frequencies up to thousands of megacycles, has solved the above problem and at the same time provided a small practical probe. A germanium rectifier is more limited by the minimum frequency which it will faithfully detect rather than by its maximum frequency of operation.

1. PEAK AND PEAK-TO-PEAK MEASUREMENTS. — The a-c electronic voltmeter discussed in paragraph 2-3.*b.*(2) (*b*)*2.* is calibrated in terms of r-m-s values of a pure sinusoidal waveform. However, because of the filter capacitor in the diode circuit, the meter current of that type voltmeter is generally proportional to the peak value of the potential under test. If the meter response is known to be in terms of r-m-s values (0.707 x peak), peak values are easily obtained by multiplying the meter readings by the factor 1.414 ($\sqrt{2}$).

It is possible by utilizing two diode tubes to rectify both the positive and negative half cycles of an applied voltage in order to charge two capacitors to the peak-to-peak value of the wave. Peak-to-peak voltmeters are especially useful in measuring the total voltage of pulses and similar waveforms.

Several electronic voltmeters have been developed principally for the peak, or peak-to-peak measurement of complex waves, including pulses. These voltmeters usually incorporate special provisions, which are not found in the typical electronic voltmeter, for increasing the accuracy of peak voltage measurements. When peak potentials are measured, especially when short pulses are involved, two new factors must be taken into consideration: (1) the transient response of the metering circuits and (2) the mark/space ratio of the waveform. The transient response is the

ability of the meter to measure pulses having not only a short duration and a low rate of repetition, but also a rapid rate of rise of the leading edge, or "transient" part, of the waveform. The mark/space ratio is the ratio of pulse width to the interval between pulses. If this ratio is high or varies from pulse to pulse, the accuracy of the meter will be seriously affected.

2-4. CAPACITORS AND CAPACITANCE MEASUREMENT.

Capacitance is that property of a circuit which produces an electrostatic field when two conducting bodies separated by a dielectric material have a potential applied to them. The magnitude (farads) of the capacitance depends upon the area of the conductors, the distance between them, and the nature of the dielectric traversed by the electrostatic lines of force set up by the difference of potential between the conductors.

Capacitors incur various losses, due to such factors as resistance in the conductors (plates) or leads, current leakage, and dielectric absorption, all of which contribute to the power factor (or dissipation factor) of the capacitor. Theoretically, the power factor of an ideal capacitor should be zero; however, the losses listed above cause the power factors of practical capacitors to range from zero to a possible 100 percent. The average power factor for good capacitors, excluding electrolytics, is 2 to 3 percent. Current leakage, which is an inverse function of frequency, is important only at the lower frequencies and becomes negligible as the higher frequencies are reached. Dielectric absorption (sometimes referred to as dielectric viscosity) results in losses that produce heat, and has the same effect as resistance in series with the capacitor.

a. TYPES OF CAPACITORS.—In the manufacture of capacitors a great many materials could be utilized as dielectrics; however, the following is a brief discussion of some of the commonly used dielectrics.

(1) PAPER.—Impregnated paper, which is the most commonly used dielectric, is relatively inexpensive but has the disadvantage of possessing appreciable losses due to dielectric hysteresis when used on alternating voltages. These losses, similar in character to magnetic hysteresis, are manifested in the form of heat generated in the dielectric and contribute to make the power factor greater than zero. Practical values for paper capacitors range from .001 microfarad to 15 microfarads. Actually, paper capacitors are sometimes made as large as 50 to 75 microfarads.

(2) MICA. — Mica capacitors consist of two sets of metal-foil plates separated by thin sheets of mica. Mica is used in capacitors because of its excellent dielectric properties and high breakdown voltage, and also because it can be split into sheets of definite thickness. Tabs are attached to each metal-foil plate for external connection. The unit is provided with lugs (or pigtail leads) and then molded in a bakelite cover. Capacitors utilizing mica as a dielectric are characterized by low losses and long useful life. A version, called a silvered-mica capacitor, has plates which consist of silver plating on the mica dielectric. The latter type has a temperature coefficient which is less than that of foil types. However, since expense is a factor, mica capacitors are not used so extensively as paper capacitors. Practical values for these capacitors range from 10$\mu\mu$f to 10,000$\mu\mu$f.

(3) D-C ELECTROLYTIC. — The d-c electrolytic capacitor makes use of the fact that aluminum (and certain other materials), when placed in a suitable solution and made the positive electrode, forms a thin insulating surface film that withstands a considerable voltage and at the same time has a high electrostatic capacitance per unit area of film. The thickness of the film depends upon the amplitude of the voltage used in its formation, higher voltages resulting in thicker films. The film gradually disintegrates if the impressed voltage is removed and is again formed when the voltage is reapplied; the forming action is accompanied by a large leakage current, which soon drops to normal (approximately 200 microamperes per microfarad for 450 volts working voltage). Continuous operation over a period of several hours further drops the leakage current to a few microamperes per microfarad. Operation of this type of electrolytic capacitor for a considerable period of time at a voltage lower than the forming voltage causes the thickness of the film to decrease, and as a result the capacitance increases. To maintain the oxide film intact, a positive potential must be applied to the anode; hence, the use of these capacitors is restricted to direct current only. (Note: Electrolytic capacitors are also designed for a-c applications by placing two positive electrodes in one container. When connected to an a-c source, the electrodes produce a rectifying effect; hence, they are not polarized. An example of this type of capacitor is the a-c motor-starting capacitor.) Voltages in excess of the working voltages may puncture the film, however, if the applied voltage is reduced, the healing action of the electrolytic will sometimes restore the film. Because large losses accompany the use of electrolytic capacitors, they are principally used in filter circuits, where the losses can be tolerated. Practical values for these capacitors range from 5 μf to 2000 μf.

(4) AIR.—Variable capacitors employing an air dielectric are used to adjust the resonant frequency of tuned circuits whenever a variable ca-

pacitor having small losses is required. Some of these small losses, which contribute to an increase in the power factor, are due to a charging current in the plates and leakage associated with the insulators that isolate the stator from the rotor. Other losses are incurred by the coupling shaft which connects the stationary plates of the variable air capacitor. Practical values for these capacitors range from 5$\mu\mu$f to 600$\mu\mu$f for the maximum capacitance setting.

(5) CERAMIC. — Capacitors using ceramic dielectrics on which a deposit of silver is plated to form the conductors (plates) are similar in size to the mica type. However, a ceramic capacitor can be made considerably smaller than a mica capacitor for a given capacitance, because certain ceramics have dielectric constants that are much greater than that of mica. With the higher dielectric constants, however, there is usually associated a high and non-linear temperature coefficient and somewhat higher losses. In addition to their compactness, these capacitors can be designed to have either a positive or negative temperature coefficient, or they can be made so that they are essentially unaffected by temperature. Practical values for these capacitors range from about 1$\mu\mu$f to 1μf.

b. CAPACITANCE MEASURING EQUIPMENTS.—Capacitor tests involving quality and value must be made in the course of electronic servicing. The following basic types of test equipment circuitry are used for capacitance measurement: the bridge circuit type, which is most accurate; the reactance type, which is often an associated test circuit incorporated into another test equipment to increase its utility, and the Q-meter, which makes use of the resonance technique.

(1) BRIDGE TYPE.—To facilitate the discussion concerning the bridge-type capacitance analyzer, the ZM-11/U Bridge will be used as a representative test equipment. Although the ZM-11/U Bridge measures, among other tests, inductance and resistance as well as capacitance, the discussion that follows covers only the measurement of capacitance. For a complete discussion concerning the capabilities of this test equipment, refer to the ZM-11/U Instruction Book (Navships 91704). To illustrate the versatility of the ZM-11/U and to aid the technician in correlating the associated test functions, an over-all schematic diagram of this test equipment is provided in figure 2-27.

The measurement of capacitance is made by a suitable bridge circuit which will be described later in the text. Incidental to the measurement of capacitance, the dissipation factor (analogous to power factor) of the capacitor under test is determined and this reading may be applied to circuit problems with due regard, however, to the frequency of the alternating current (1000 cps) used for testing. A d-c polarizing voltage is provided for application to electrolytic capacitors while measuring their capacitance value and dissipation factor. The capacitor leakage current may be determined either with or without taking the capacitance or dissipation readings.

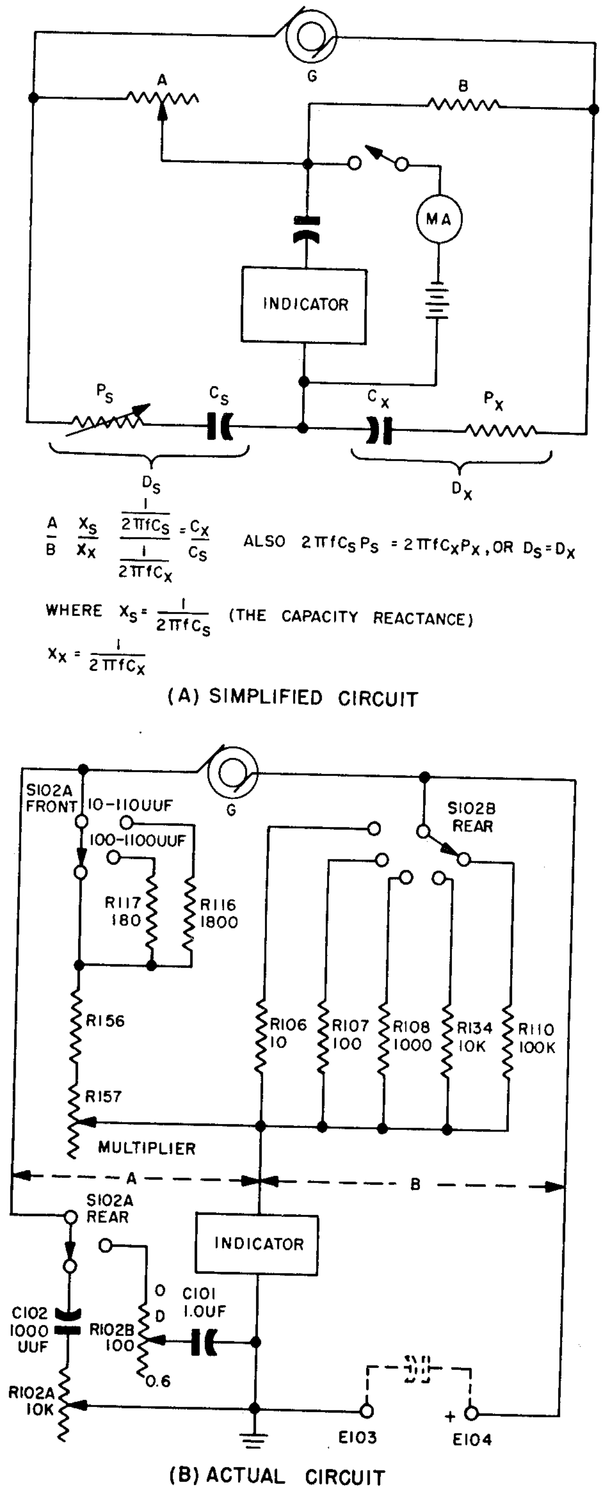


Figure 2-26. Capacitance-Bridge Circuits

1

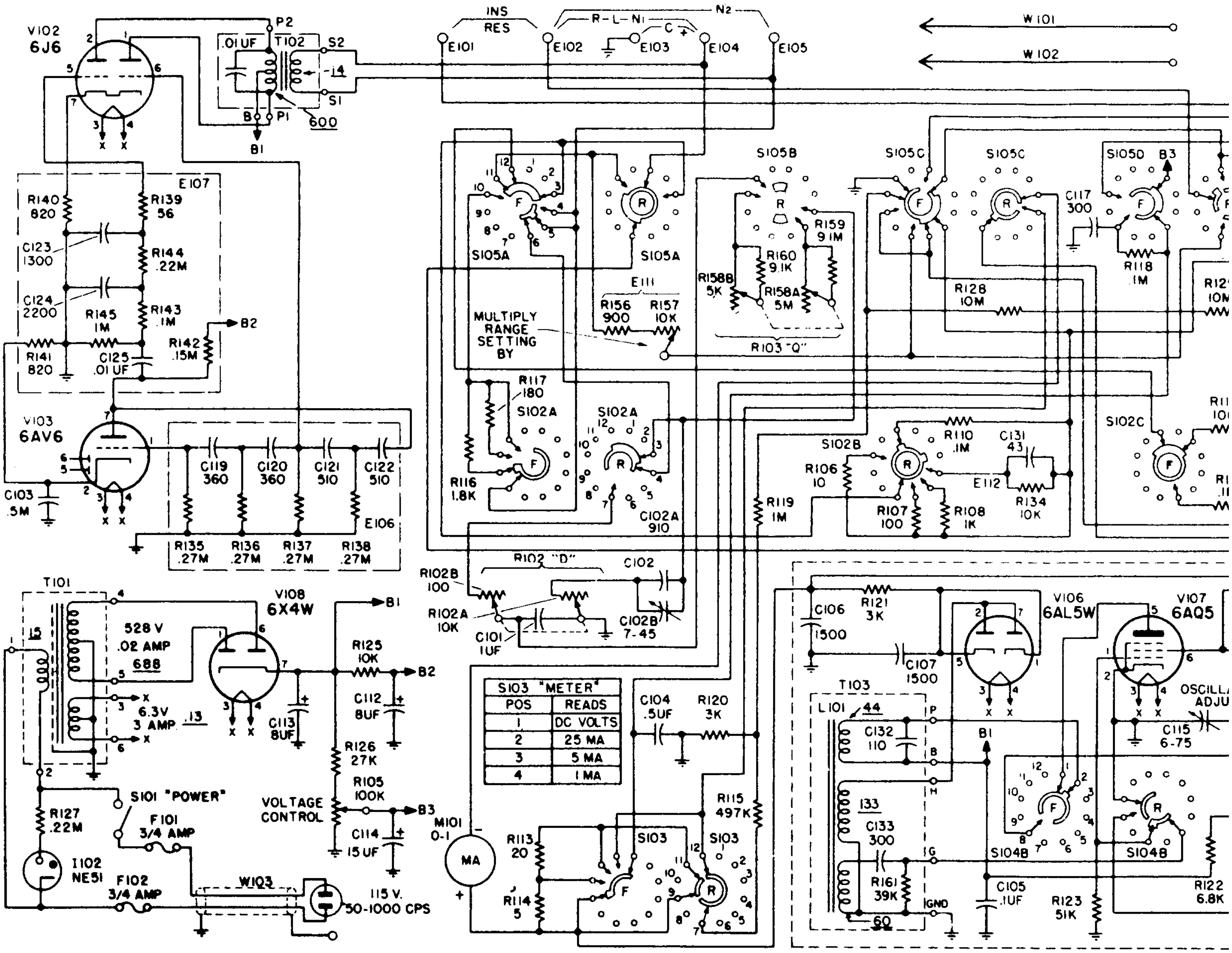
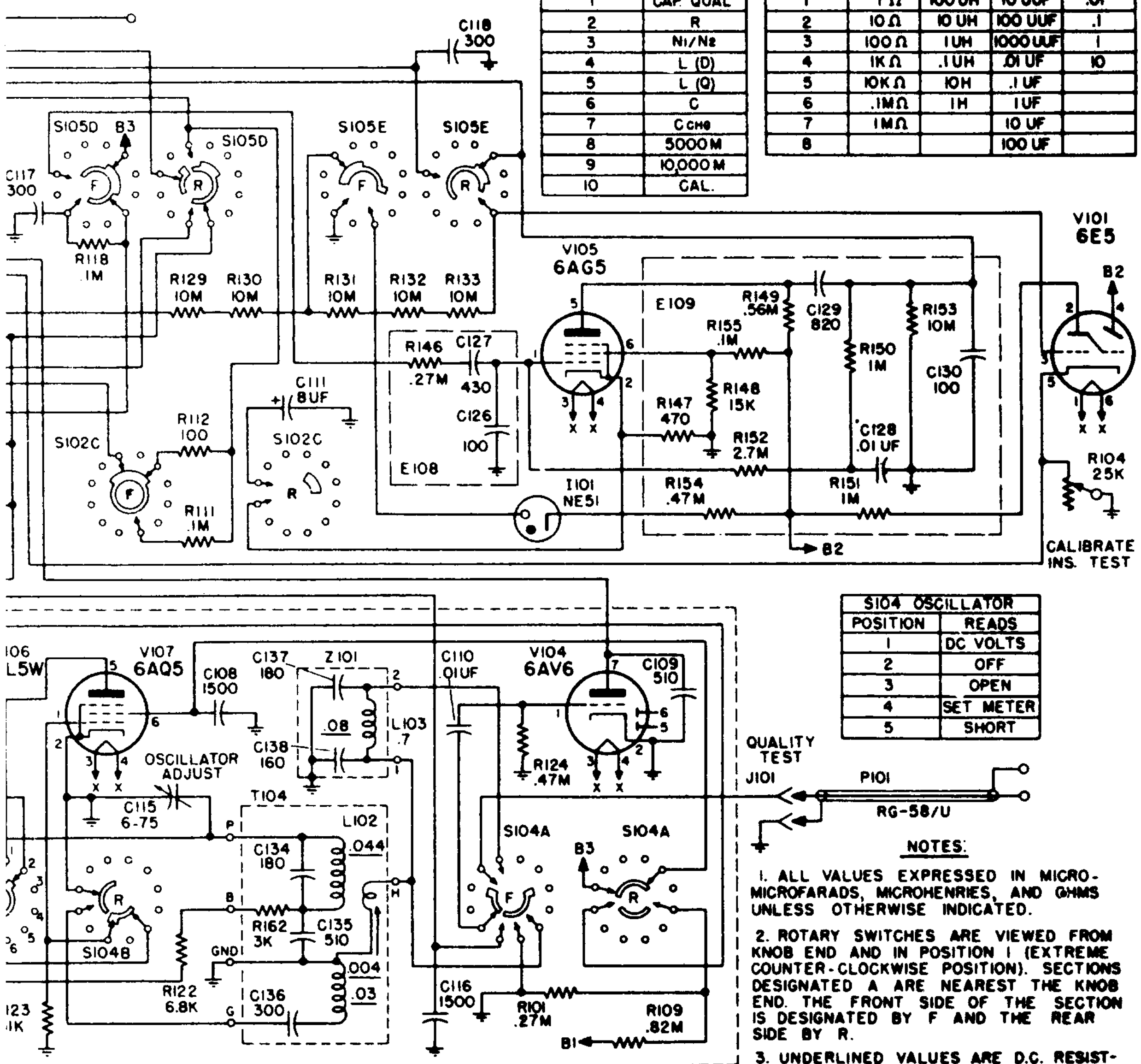

V102
6J6
P2
.01 UF
T102
S2
S1
P1
B
B1
600
INS
RES
E101
E102
R - L - N1
C +
E103
E104
N2
E105
W 101
W 102
E 107
R140
820
R139
56
C123
1300
R144
.22M
C124
2200
R145
1M
R143
.1M
R142
.15M
B2
R141
820
C125
.01 UF
V103
6AV6
C103
.5M
C119
360
C120
360
C121
510
C122
510
E106
R135
.27M
R136
.27M
R137
.27M
R138
.27M
T101
528 V
.02 AMP
688
6.3V
3 AMP
V108
6X4W
C113
8UF
C112
8UF
R125
10K
R126
27K
R105
100K
VOLTAGE
CONTROL
B3
C114
15 UF
S101 "POWER"
F101
3/4 AMP
R127
.22M
I102
NE51
F102
3/4 AMP
W103
115 V.
50-1000 CPS
S105A
S105B
S105C
S105D
R159
9.1M
R160
9.1K
R158B
5K
R158A
5M
R103 "Q"
E111
R156
900
R157
10K
MULTIPLY
RANGE
SETTING
BY
C117
300
R118
.1M
R128
10M
R117
180
S102A
R116
1.8K
C102A
910
S102B
R110
.1M
C131
43
R106
10
E112
R107
100
R108
1K
R134
10K
R119
1M
S102C
R102B
100
R102 "D"
C102
R102A
10K
C101
1UF
C102B
7-45
S103 "METER"
POS | READS
1 | DC VOLTS
2 | 25 MA
3 | 5 MA
4 | 1 MA
C104
.5UF
R120
3K
M101
0-1
MA
R113
20
R114
5
S103
R115
497K
C106
1500
R121
3K
C107
1500
V106
6AL5W
V107
6AQ5
T103
L101
44
C132
110
133
C133
300
R161
39K
60
GND
C105
.1UF
S104B
R123
51K
R122
6.8K
C115
6-75

Figure 2-27.

(2)

S105 "FUNCTION"	
POSITION	READS
1	CAP. QUAL
2	R
3	N1/N2
4	L (D)
5	L (Q)
6	C
7	CCHG
8	5000 M
9	10,000 M
10	CAL.

S102 "RANGE"				
POS	R	L	C	N1/N2
1	1 Ω	100 UH	10 UUF	.01
2	10 Ω	10 UH	100 UUF	.1
3	100 Ω	1 UH	1000 UUF	1
4	1K Ω	.1 UH	.01 UF	10
5	10K Ω	10 H	.1 UF	
6	.1M Ω	1 H	1 UF	
7	1M Ω		10 UF	
8			100 UF	



S104 OSCILLATOR	
POSITION	READS
1	DC VOLTS
2	OFF
3	OPEN
4	SET METER
5	SHORT

NOTES:

1. ALL VALUES EXPRESSED IN MICRO-MICROFARADS, MICROHENRIES, AND OHMS UNLESS OTHERWISE INDICATED.
2. ROTARY SWITCHES ARE VIEWED FROM KNOB END AND IN POSITION 1 (EXTREME COUNTER-CLOCKWISE POSITION). SECTIONS DESIGNATED A ARE NEAREST THE KNOB END. THE FRONT SIDE OF THE SECTION IS DESIGNATED BY F AND THE REAR SIDE BY R.
3. UNDERLINED VALUES ARE D.C. RESISTANCE IN OHMS OF WINDINGS.

Figure 2-27. Over-all Schematic Diagram of a Typical Bridge-Type Capacitance Analyzer

Part (A) of figure 2-26 shows a simplified bridge circuit which will be used to explain the measurement of capacitance. As can be seen from the balance equation, shown in the same figure, it is actually the capacitative reactance rather than the capacitance which is balanced. In addition to its reactive property, the capacitance under test always exhibits some loss. This loss may have the characteristics of either a shunt or series resistance or may be, perhaps, a combination of both. Regardless of its true nature, the loss can always be represented by a simple series resistance which is shown in part (A) of the same figure as P_x. This loss can be balanced by the calibrated series resistance P_s shown in the standard arm side. Rather than calibrate this control in terms of resistance it is an operational convenience to calibrate it in terms of dissipation factor D, as defined in part (A) of figure 2-26. The control then provides the means for completing the capacitance balance and its dial reading indicates a loss figure for the capacitor under test.

Part (B) of figure 2-26 shows the actual circuit arrangement used for the measurement of capacitance. This arrangement corresponds to the C position of the FUNCTION switch as shown by the notation in the upper right hand corner of figure 2-27. Two capacitance standards are used, and, with the above arrangement, eight continuous and progressive capacitance ranges are provided. Because two values of standard capacitance are used, two values of the dissipation factor must also be provided. These controls are ganged on one shaft to which is attached the D panel dial. The 1000 $\mu\mu$f standard is used through the first four capacitance ranges, 10 $\mu\mu$f to 0.11 μf. Capacitors tested in this range usually are constructed with mica or paper as a dielectric and cannot have a very high dissipation factor before their condition becomes suspect. For this reason, with the 1000 $\mu\mu$f standard, the dissipation factor D was limited to a maximum value of 0.06. This provides best readability in the region of usual interest.

The remaining four capacitance ranges cover capacitor values from 0.1 μf to 1100 μf. In the higher portion of this range, the capacitor under test is apt to be of electrolytic constructions and a wider range of the dissipation factor is required to balance acceptable capacitors. Therefore, for the latter four ranges, the dissipation factor covers from 0 to 0.6.

The stray capacitance existing between the panel connections, E-103 and E-104, together with the connecting wiring and switch contacts amounts to about 17 or 18 $\mu\mu$f. This is compensated for in the following manner. It should be noted in part (B) of figure 2-26, that for the 10 to 110 $\mu\mu$f range, the resistance of the "A" arm is 100 ohms per $\mu\mu$f, and that for this range an 1800 ohm resistor inserted in the "A" arm has the effect of subtracting 18 $\mu\mu$f from the reading of the MULTIPLY RANGE SETTING BY dial. Similarly, on the 100 to 1100 $\mu\mu$f range, insertion of 180 ohms has the same effect. The above resistors, R116 and R117 respectively, are inserted automatically by suitable contacts on the FUNCTION and RANGE switches. The effect of the residual capacitance on the higher ranges is negligible, and consequently, is not compensated for.

D-C electrolytic capacitors often require the application of a d-c voltage in order to exhibit the same capacitance value and dissipation factor that they would in actual circuit operation. If the capacitor is in good condition, the first application of a d-c voltage, equal or less than the working voltage, causes a sudden rush of current which falls back to a smaller steady value after 3 or 4 minutes. This steady current flow is known as the leakage current. When a stable value of current is reached, the capacitor is said to be polarized. For the testing of electrolytic capacitors under simulated circuit conditions, a hypothetical battery and meter are shown in part (A) of figure 2-26. Series capacitor blocks the battery from the indicator and the d-c flow is through the "B" arm and the capacitor under test C_x (and P_x). The d-c leakage current may be read on the meter. In the typical bridge type analyzer, the battery function is replaced by a power supply of the r-f type.

The panel meter M101 is normally connected as a 0 to 500 voltmeter, so that the technician can measure the potential applied to the capacitor under test. When METER switch S103 is turned to the MA position, current ranges of 25, 5 and 1 milliampere (see shunts R113 and R114) are selected in turn to obtain a measurement of the leakage current through the electrolytic capacitor. It should be noted that the d-c power supply and meter circuits are so connected that there is no interference with the normal operation of the capacitance measuring bridge circuit, and also that the dissipation factor of the capacitor may be obtained while the capacitor is polarized.

(2) REACTANCE TYPE. — The reactance type of capacitance measuring equipment makes use of the principle that, if an a-c voltage (usually 6.3 volts) of fixed frequency is applied across a capacitor and a resistor in series, the voltage drop produced across the reactance of the capacitor by the resulting current flow is inversely proportional to the capacitance. The voltage drop is used to actuate a meter which is calibrated in capacitance values. This test equipment gives approximate values only, and, like the ohmmeter, is used mostly when portability and speed are of first consideration. The accu-

racy of the reading is less for capacitors that have a high power factor. In such a capacitor, the losses incurred effectively place a certain amount of resistance in series with the capacitive reactance. The effect of this resistance, when the capacitor is measured, is to cause a greater voltage drop across the capacitor, because the drop is due—not to the reactance—but to the impedance, which is made up of both the reactance and the resistance. Therefore, it can be seen that the capacitance indicated by the analyzer is lower than the actual value.

Figure 2-28 shows a simplified schematic diagram of the capacitance measuring section of a typical (reactance type) electronic volt-ohm-capacitance-milliammeter 6.3 volts ac, taken from the filament supply, is applied to a network of resistors, some or all of which are used as dropping resistors in series with the capacitor under test, depending upon the capacitance range selected by a seven-position switch. The voltage developed across the capacitor is fed to the cathode follower (impedance-matching device) and then rectified by means of the 6X5. The rectified voltage is applied to the bridge circuit, which causes proper meter deflection for any selected range.

Analyzers of this type have an appreciable internal wiring capacitance which is negligible on the higher ranges but affects the accuracy considerably on the two lower ranges. For measurements taken on these two ranges, the initial meter reading should be subtracted from the final reading to produce the true value of the capacitor under test. The test equipment should be zero-adjusted on one of the higher ranges that is not affected by this internal capacitance.

c. EVALUATION OF MEASUREMENTS. — A knowledge of capacitance tolerances is a prerequisite to proper evaluation of completed tests. Since these tolerances vary over a wide range, depending upon the type of capacitor, the value of the capacitance, and the voltage rating, it is possible that capacitors may be erroneously rejected because of high test value. Because of a particular use or circuit application, some capacitors are permitted an even wider variation of capacitance tolerance than is generally known to the technician.

(1) ELECTROLYTIC CAPACITOR TOLERANCES. — The testing of electrolytic capacitors plays an important role in the maintenance of electronic equipments. During trouble shooting, when open or shorted capacitors are located, there is no problem as to their rejection. However, for those capacitors which do not fall into either of these categories, acceptance or rejection becomes a more difficult matter. In the process of corrective maintenance, if a defective d-c electrolytic is replaced

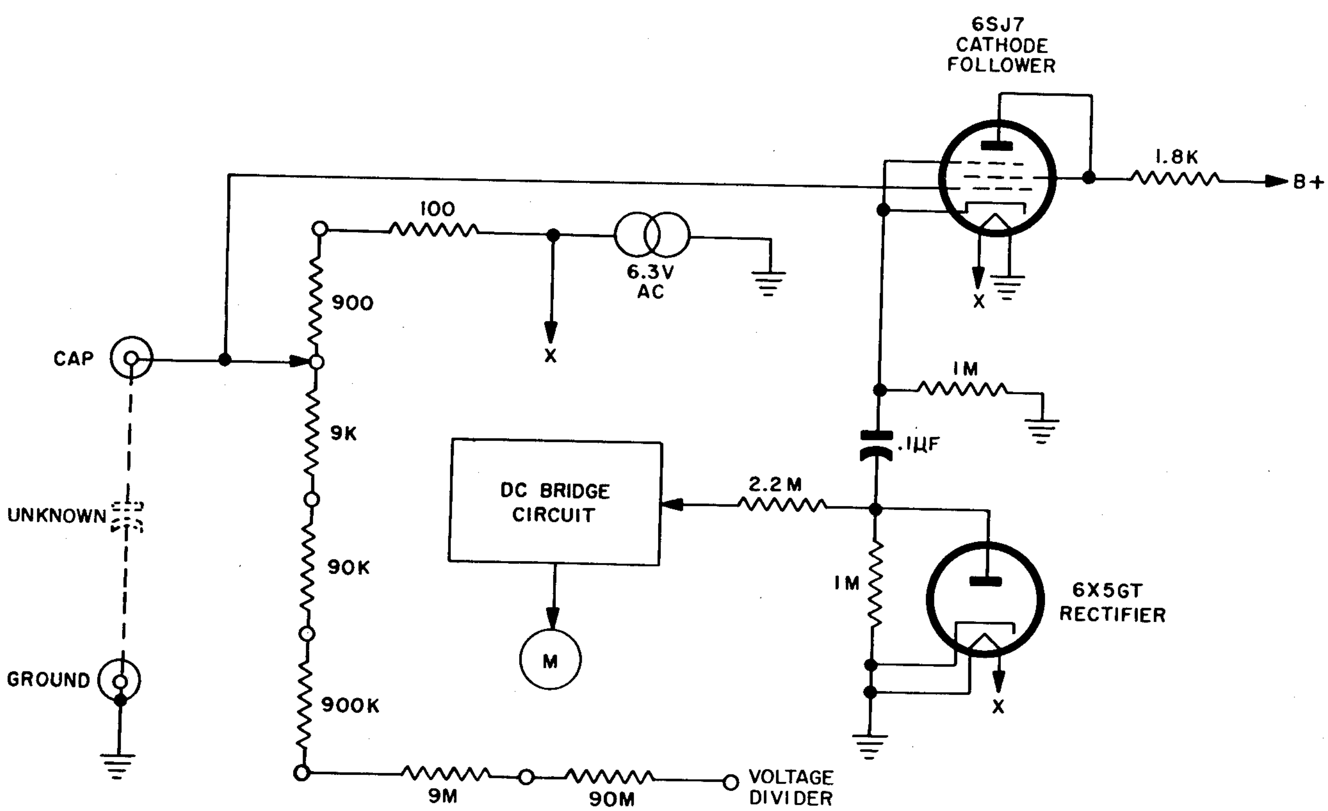


Figure 2-28. ***Simplified Schematic Diagram of Capacitance-Measuring Section Taken from a Typical Electronic Volt-Ohm-Capacitance-Milliammeter***

with one having a high leakage current, the new capacitor will either fail in a very short time or cause poor over-all operation of the equipment concerned.

The direct-current leakage of an electrolytic capacitor, when measured with an acceptable Navy-Type analyzer, should not exceed the current value which can be calculated from the information listed in Table 2-2.

TABLE 2-2. ELECTROLYTIC CAPACITOR LEAKAGE CURRENT CHART

RATED WORKING VOLTAGE (Volts)	ALLOWABLE LEAKAGE CURRENT Milliamperes/microfarad
15 to 100	0.1
101 to 299	0.2
300 to more	0.5

For example, if a 16-μf capacitor rated at 450 volts (working voltage) is to be tested, multiply the value of the capacitor (16 $\mu\mu$f) by the allowable leakage current for that voltage category (0.5 ma). The total allowable leakage current therefore is 8 milliamperes.

The above table can be used for either wet or dry electrolytics. If the direct-current leakage exceeds the calculated allowable leakage, the capacitor should be discarded. Capacitors in spares (especially wet electrolytics) should be tested periodically to ensure that the leakage current remains within the prescribed limits. Note that it is necessary to re-form capacitors that have been idle for some time. For a discussion concerning re-forming electrolytics, refer to paragraph 2-4.*a.*(3).

(2) PAPER CAPACITOR TOLERANCES. —From the circuit standpoint, the capacitance tolerance of paper capacitors used for coupling and bypassing is rather wide, and compares with the tolerance for electrolytic filter capacitors. Contrary to the wide-spread impression current among many technicians, metal-encased capacitors are not necessarily manufactured to close tolerances. Table 2-3 shows the standard capacitor tolerances for paper tubular capacitors.

TABLE 2-3. TOLERANCES FOR PAPER TUBULAR CAPACITORS

CAPACITOR LETTER CODE	CAPACITOR TOLERANCE (percent) Plus	Minus
K	10	10
L	15	15
V	20	10
M	20	20
W	25	0
X	40	15
Y	60	25

(3) MICA AND CERAMIC CAPACITOR TOLERANCES. — Mica and ceramic capacitors, unless otherwise color-coded or marked, are generally held within ±20 percent of their nominal value. Standard color-coded capacitors are available in tolerances of ±2, ±3, ±5, ±10 and ±20 percent.

2-5. INDUCTORS AND INDUCTANCE MEASUREMENT.

A current flowing through a conductor produces a magnetic field around that conductor. If the conductor is formed into a coil, a stronger magnetic field is set up. The relationship between the strength of the field and the intensity of the current causing it is expressed by the inductance of the coil (or conductor). When the current producing the magnetic field ceases, the energy of the magnetic field is returned in part to the circuit source in the form of a reverse current. Inductance, then, is the ability of a coil to function as a storehouse of energy in magnetic form, and is determined by the shape and dimensions of the coil. Inductance is measured in henries, millihenries (.001 henry), or microhenries (.000001 henry).

a. INDUCTORS.—Inductors can be described generally as circuit elements used to introduce inductive reactance into a-c circuits. An inductor is essentially a coil of wire wound around a form utilizing a core of air, magnetic metal, or nonmagnetic metal. A core of magnetic metal produces greater inductance (for a coil of given size and number of turns) than does an air core; a core of nonmagnetic metal produces less.

(1) COIL CONSTRUCTION.—Many types of coil windings have been devised to obtain different characteristics. Figure 2-29 shows sev-

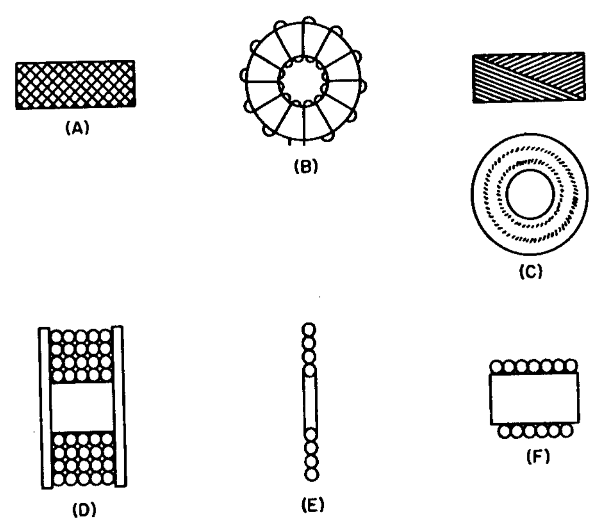


Figure 2-29. Types of Coil Windings

eral types. Part (A) of this figure illustrates a honeycomb wound coil. This type provides comparatively low distributed capacitance. Part (B) of the same figure shows a toroid wound coil. This type is wound in one or more layers and is essentially a coil bent so that its ends join. This shape results in cancellation of the external field — a characteristic which is useful in many circuits. Part (C) shows a universal wound coil which is characterized by compactness and fairly high Q (figure of merit or storage factor). Part (D) shows a multilayer coil used when a high inductance is required. Part (E) illustrates a flat or pancake coil. This type is not often used singly; instead several are connected in series. Part (F) shows a simple, single layer solenoid used when low inductance values are needed.

(2) R-F INDUCTORS.—At frequencies in the HF and higher regions of the spectrum, coils of small size and high Q are generally required. These are usually single-layer solenoids with air or metallic cores. Since comparatively low values of inductance are required, this type of coil is very compact and relatively high values of Q are obtained. At frequencies in the LF and MF regions of the spectrum, single-layer solenoid, universal, spiral, and other types of windings are used. When size is a factor, the more compact windings are preferred to the solenoid type of coil. At frequencies below 500 kc. the single-layer solenoid is too large and the more compact types are used exclusively.

(*a*) METALLIC CORES.—At the relatively higher frequencies (LF and above), eddy-current losses preclude the use of solid or laminated metal cores. Instead, finely ground iron (or alloy) particles are mixed with a bakelite filler and an insulating varnish binder and pressed into the form of a cylindrical slug. This construction insulates the iron particles from one another, and thus reduces eddy-current losses. Coils utilizing powdered-iron cores are compact with high values of Q. Variation in inductance is accomplished by mounting the iron slug so that it can be moved in and out of the coil along the coil axis.

(3) FILTER CHOKES.—Choke coils used in filters for elimination of powerline hum are always of the iron-core type. They are manufactured in inductance values of 5 to 30 henries. Iron-core chokes are often used in circuits carrying both direct current and alternating current. To prevent saturation (increase of current does not produce corresponding increase of flux density) of the iron core, one or more air gaps are always built into the core. The total gap must be wide enough to prevent magnetic saturation, but must not be so wide as to reduce the inductance below that required as a minimum.

(4) INDUCTOR LOSSES.—The resistance of the conductor with which an inductor is wound is the most important factor contributing to the losses of the inductor. Losses due to this resistance increase with increased frequency, because skin effect results in concentration of current near the outer surface of the wire. Skin effect, which is negligible at low frequencies, can be an important factor at high frequencies. Other contributing factors to inductor losses are: (1) eddy currents set up in the core and surrounding objects (if they are conductors), (2) the dielectric properties of the form used for the coil and surrounding objects, and (3) hysteresis in the core and surrounding objects if they are magnetic metals. Losses occur as a result of the dielectric properties of the coil form because of the distributed capacitance of the inductor; for example, between turns, between the terminals and leads, etc. To some extent the core (and surrounding objects) serves as a dielectric of the distributed capacitance, and the resulting dielectric losses contribute to the over-all losses of the inductor.

(*a*) STORAGE FACTOR Q.—As was discussed earlier, an inductor has the ability to act as a storehouse of magnetic energy. However, because of the various loss factors described above, all of the energy stored in the magnetic field is not returned to the source as the applied voltage decreases to zero. The losses of an inductor may be represented by an equivalent series resistance, having a value such that it would dissipate an amount of energy equal to the total amount dissipated by the inductor. The losses of an inductor may be expressed in terms of the ratio of its inductive reactance to its equivalent series resistance. This ratio is referred to as the Q of the inductor, and is stated in equation form as $Q = X_L/R$.

b. INDUCTANCE MEASURING EQUIPMENTS.—Following the trouble-shooting of an electronic equipment and before repair has been effected, various inductors (coils, chokes, etc.) may have to be tested for their condition and suitability for installation in a particular circuit. For the measurement of inductance, the following basic types of test equipment circuitry are used: (1) the bridge circuit type, which is most accurate; and (2) the reactance type, which is often an additional test circuit incorporated into another test equipment to increase its utility.

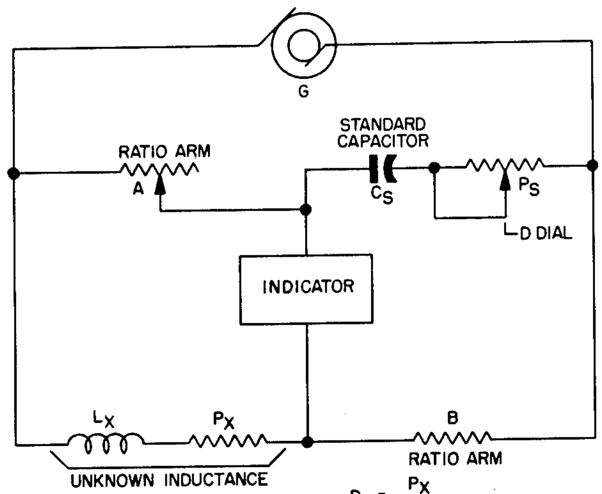
(1) BRIDGE TYPE.—In paragraph 2-4, the measurement of capacitance was discussed using the Bridge Capacitance-Inductance Resistance ZM-11/U as a typical test equipment. Since the measurement of capacitance and inductance are interrelated, the existing capacitance standards

and loss controls of this test equipment are utilized whenever possible. A wider range of dissipation must be provided to accommodate the practical value of inductors. For over-all circuit information of the ZM-11/U, the technician should refer to figure 2-26. In order to accommodate the extensive range in inductor loss factors, two basic bridge circuits are utilized: the Hay bridge and the Maxwell bridge.

(*a*) HAY BRIDGE.—The Hay bridge measures inductance by comparing it with a capacitance; it differs from the Maxwell bridge in that the resistance associated with the capacitance is a series instead of a shunt resistance. The inductance balance depends upon the losses (Q) of the inductance. The Hay bridge is employed for inductors having low losses (low D dial reading or high Q) at 1000 cps. This circuit is in effect when the FUNCTION switch is turned to the L(D) position, and its basic balance equations are shown in part (A) of figure 2-30. The equations numbered (3) and (4) assume that D^2 may be neglected with respect to 1.0 under certain conditions. For a D dial reading up to 0.05 the error resulting from the above assumption is 0.25 percent. Above this point the error increases rapidly and appreciably affects the basic accuracy of the test equipment. This limitation is expressed on the front panel of the test equipment as follows: IF $D_L > .05$ ON L(D); REBALANCE ON L(Q). In other words, if the dissipation (D_L) of an inductor, as read on the D dial when using the Hay bridge (FUNCTION switch set to L(D) position) exceeds 0.05, then a change must be made to the Maxwell bridge (FUNCTION switch set to L(Q) position), which is discussed in the following paragraph. The loss factor of the inductor under test is then balanced in terms of the Q of the inductor.

(*b*) MAXWELL BRIDGE.—The Maxwell bridge, shown in part (B) of figure 2-30, measures inductance by comparing it with a capacitance and (effectively) two resistances. This bridge circuit is employed for measuring the inductance of inductors having greater losses than is expressed by a D dial reading of 0.05. For such inductors it is necessary to introduce, in place of the series control (D dial), a new loss control (Q dial) which shunts the standard capacitor. This control, which becomes effective when the FUNCTION switch is turned to the L(Q) position, is conveniently calibrated in values of Q, the storage factor of the inductor under measurement.

Comparison of equation (3) shown in part (A) of figure 2-30 with equation (1) of part (B) of the same figure shows that the balance for inductance is the same for either bridge circuit. This permits use of the same markings on the RANGE switch



$$D_L = \frac{P_X}{2\pi f L_X}$$

$$L_X = \frac{ABC_S}{1+(2\pi f C_S P_S)^2} = \frac{ABC_S}{1+D^2} \quad (1)$$

$$P_X = \frac{AB(2\pi f C_S)^2 P_S}{1+(2\pi f C_S P_S)^2} = \frac{AB(2\pi f C_S)^2 P_S}{1+D^2} \quad (2)$$

BALANCE EQUATIONS MUST BE SIMULTANEOUSLY BROUGHT ABOUT TO BALANCE BRIDGE

WHEN D^2 IS SMALL WITH RESPECT TO 1

$$L_X = ABC_S \quad (3)$$

$$P_X = AB(2\pi f C_S)^2 P_S \quad (4)$$

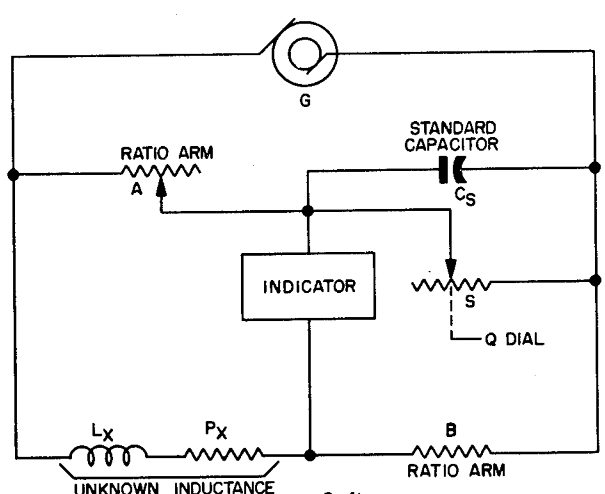
DIVIDING (4) BY (3) AND $2\pi f$:—

$$\frac{P_X}{2\pi f L_X} = 2\pi f C_S P_S = D \quad (5)$$

BASIC CALIBRATION OF 'D' DIAL

THIS IS $\frac{1}{Q}$ OR D OF THE INDUCTOR

(A) HAY BRIDGE



$$Q_L = \frac{2\pi f L_X}{P_X}$$

$$L_X = ABC_S \quad (1)$$

$$SP_X = \frac{L_X}{C_X} \quad (2)$$

MUST BE SIMULTANEOUSLY TRUE TO BALANCE BRIDGE

SINCE $Q_L = 2\pi f \frac{L_X}{P_X}$ AND FROM (2) $\frac{L_X}{P_X} = C_S S$

$Q_L = 2\pi f C_S S$ (3)

(B) MAXWELL BRIDGE

Figure 2-30. Basic Bridge Circuits Used for Inductance Measurements

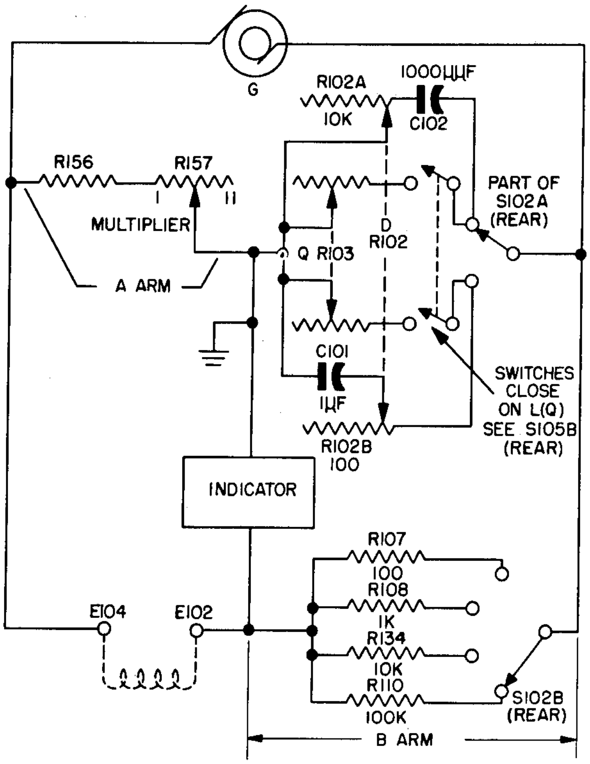


Figure 2-31. Combined Bridge Circuits Used for Inductance Measurement

for both the L(D) and L(Q) positions of the FUNCTION switch. The combined circuit of the Hay and Maxwell bridges used in the ZM-11/U is shown in figure 2-31.

(*c*) OPERATION. — To measure inductance with the ZM-11/U, proceed as follows: Connect the inductor under test to the post marked L (second and fourth from left). Turn the FUNCTION switch to the L(D) or L(Q) position depending on the probable loss factor of the inductor under test. As a rule, inductors with powdered-iron cores (designed for operation in the a-f range) fall within the loss range of L(D) position of the FUNCTION switch, and r-f and i-f inductors fall within the loss range of the L(Q) position. If the operator is unable to decide between the L(D) or L(Q) positions, he should attempt a balance on the L(Q) position first. Turn the RANGE switch to a reasonable setting within the L ring, and attempt a balance by rotating the MULTIPLY BY dial. If any indication of balance is attained, try to complete it by simultaneous adjustment of the Q dial. If the condition of balance is approached at either end of the MULTIPLY BY dial, the operator should try the next higher or lower position of the RANGE switch and complete the bridge balance.

If the condition is reached where a partial balance is attained on the MULTIPLY BY dial but lack of range on the Q dial does not permit completion of the balance, the inductor under test probably has a Q factor greater than 20. The operator should then change the FUNCTION switch to the L(D) position. Using the D dial, balance should now be attained. (Note: Mechanical interlocks between the D and Q dials make it necessary to return either one to its initial position before the other can be operated.)

After bridge balance has been reached as shown on the indicator tube, read the position of the RANGE switch on the L ring and multiply this reading by the indication on the MULTIPLY BY dial. The product, then, is the inductance of the inductor under test. Note the indication of the D or Q dial at which balance was attained.

Note

If balance was reached in one of the reverse color ranges (10 henries or 1 henry) of the RANGE switch, the indication as read on the D dial must be multiplied by the factor 10.

If the apparent value of dissipation D, as measured on the L(D) position of the FUNCTION switch, is greater than 0.05, the balance point may have been missed on the L(Q) function; the operator should repeat the test on that function for greatest accuracy of inductance determination. The equivalent series resistance (at 1000 cps) of the inductor can be determined by substituting the measured values in one of the following formulas, the selection of the formula depending upon whether Q or D is measured: $R = 2\pi fL/Q$ or $R = 2\pi fLD$ (L in henries).

(2) REACTANCE TYPE. — The reactance type of inductance measuring equipment makes use of the principle that, if an a-c voltage of fixed frequency is applied across an inductor (and a resistor in series), the voltage drop produced across the reactance of the inductor by the resulting current flow is directly proportional to the value of the inductance. By reference to paragraph 2-4.*b*.(2), it should be readily seen that inductance measurement utilizing the reactance type method is identical to capacitance measurement using that same method with the exception that current flow is directly proportional to the value of inductance, rather than inversely proportional as in the case of capacitance. It follows then that if a reactance type capacitance measuring equipment is provided with a chart which converts the capacitance readings to equivalent inductance values, and a proper range multiplying factor, the same test setup can be used to measure both capacitance and inductance. In practice, test equipments using the reactance type method for capacitance determination usually provide an inductance conversion chart. Because the current flowing through the inductance under test is directly pro-

portional to the value of inductance, the reciprocals of the capacitance range multipliers must be used; for example, a multiplier of 0.1 becomes 1/0.1 or 10 and a multiplier of 100 becomes 1/100 or 0.01. Figure 2-28 and the text of paragraph 2-4.*b*.(2) explain the circuit operation of the reactance type method.

The reactance type equipment gives approximate values only and, like the ohmmeter, is used only when portability and speed are of first consideration. If the ohmic resistance of the inductor is low, the inductance value obtained from the conversion chart can be used directly. If the ohmic value (measured with an ohmmeter) is appreciable, a more accurate value of inductance can be obtained by use of the following formula: $L = \sqrt{Z_L^2 - R_L^2}/2\pi f$, where L is the inductance, Z_L is the impedance of the inductance under test, f is the frequency, and R_L is the ohmic resistance.

2-6. POWER MEASUREMENT.

Comparison of mechanical and electrical power shows that work is accomplished, mechanically, if force is accompanied with simultaneous motion. Mechanical power then is the time rate of performing work. Since voltage compares with mechanical force and current with velocity, electrical power can also be considered as the time rate of performing work, or it may be expressed as the rate at which energy is expended, because energy may be defined as the ability to do work.

a. POWER IN A-C CIRCUITS. — Mechanically no power is expended unless force and velocity are present at the same time; electrically no power is expended unless current flow (velocity) occurs at the same time as the voltage (force) is applied. In a purely resistive a-c circuit (or a d-c circuit) voltage and current always act simultaneously, and as a result the power expended always equals $E \times I$, or (by Ohm's law) $I^2 \times R$. In an a-c circuit which is not purely resistive, the maximum current occurs before or after the maximum voltage point (after a steady state condition has been reached). In effect, this action causes some of the total energy (wattless component) to be returned to the source. The amount of energy returned determines the power factor of the circuit, so that the true energy expended equals $E \times I \times PF$.

Power measurements made in electronic servicing may include primary power measurements and input and output power (signal) measurements. Different frequencies and circuit applications require various types of measuring instruments. To facilitate the discussion of power measurement, the spectrum will be divided into three main divisions: (1) The power-line frequencies, extending from 25 to 800 cps; (2) the audio and very-low radio frequencies (VLF), covering the range from 20 cps to 30 kc; and (3) the radio frequencies. Since the radio-frequency region is very broad, it will be subdivided into two parts: One will extend from the low-frequency (LF) through the very-high-frequency (VHF) regions covering 30 kc to 300 mc; and the other will extend from the ultra-high-frequency (UHF) through the extremely-high-frequency or microwave regions, covering from 300 mc to approximately 100,000 mc.

(1) LINE-FREQUENCY POWER MEASUREMENTS. — The electrodynamometer (or wattmeter) is generally utilized to measure power taken from a-c (or d-c) lines that are used to supply large amounts of power for equipment, etc. For an explanation of the construction and theory of operation of the electrodynamometer, refer to paragraph 2-2.*a*.(2).

Dynamometer type wattmeters automatically compensate for the power factor of the circuit. These meters always read the true power expended, regardless of the lag or lead of the circuit current. When current lags or leads, less power is consumed than when the same current is in phase with the voltage, resulting in a power factor of less than unity. With out-of-phase currents through the current coil of the dynamometer, a current peak never occurs at the same instant as a voltage peak in the voltage coil, resulting in less pointer deflection than when current and voltage are in phase.

(2) AF AND VLF POWER MEASUREMENTS.—Because the human ear responds more readily to ratio changes rather than to absolute changes, and also because of the need for some unit which expressed the comparison of output power to input power, a unit known as the bel was originated for use in power measurements. In the audio range (20 cps to 30 kc.), however, power measurements are primarily made in terms of a more practical unit, the decibel, which is one-tenth of a bel. Decibels normally indicate a ratio change of power, and are useful as a measure of how an electronic device affects the transmission of energy through itself (efficiency). Since the decibel is a logarithmic unit the gains (+db) and losses (−db) in a complicated circuit can be added algebraically to determine the over-all net effect of the circuit.

A few useful facts about decibels are: an increase (or decrease) of 3 db just about doubles (or halves) the power under measurement, 0 db means no change, 10 db equals 10 times, 20 db equals 100 times, 30 db equals 1000 times, and so on. Because a ratio is involved, decibels have no real meaning unless a reference level is specified. Thus, the expression, "an output signal of +20 db," is meaningless; however, if the same signal is referred to 6 milliwatts, the expression

becomes intelligible, indicating that the output is equal to 600 milliwatts. It is also possible to compute decibels by means of a voltage (or current) ratio; however, if intelligible results are to be obtained, the input and output impedances must be equal. If these impedances are not equal, the equivalent power must be computed from the voltage (or current) and the corresponding impedance and then the ratio obtained must be converted to decibels.

(*a*) DB METER. — Usually a db meter is a copper-oxide-rectifier type a-c voltmeter or an a-c electronic voltmeter calibrated in db's. As a rule the db meter is incorporated as part of a volt-ohm-milliammeter, and the same jacks and switch positions used for a-c voltage measurements are used for db measurements. When the db meter is calibrated a reference point, based on a specific power or value of voltage across a specified resistance, is selected to represent 0 db. A typical electronic voltmeter, as shown in figure 2-25, has a db scale based on 1 milliwatt across a 600 ohm load, which equals 0 db. Based on this reference point, various voltage readings are made on the low a-c voltage scale, and, after conversion to decibels by means of the appropriate formula, these readings are then marked on the scale. In order that a single calibrated db scale may be used on all db ranges, numbers (+DB) corresponding to the voltage ratios existing between the successive ranges and the low a-c range are computed for each range. These numbers, which appear on the front panel of the instrument, are then added algebraically to each successive range reading to produce the correct value for that range.

It should be clearly understood that the term decibel does not, in itself indicate power, but rather a ratio or comparison between two power levels. It is often desirable to express performance measurements in decibels. This can be done by using a fixed power level as a reference. The original standard reference level was 6 milliwatts, but to simplify calculations a standard level of 1 milliwatt has been adopted. Thus, when the expression dbm is seen, it should be understood that the reference level is 1 mw. For the use of dbm in radar testing, refer to Section 3, paragraph 3-9.*a*.(2).

(*b*) VU METER.—The vu (volume unit) meter, which is used in audio equipment to indicate the input power to a transmitter or a transmission line, is a copper-oxide-rectifier type a-c voltmeter with a standardized speed of pointer movement, speed of return, and calibration. The vu meter has a rapid rise and slow fall, which makes it easy to follow audio peaks and modulation envelope values. The scale is calibrated in the same manner as the db meter; however, 0 db corresponds to a power level of 1 milliwatt (.775 volt) across a 600 ohm load. A change of one vu is equal to a change of one db. If the zero reference of a db meter is as stated above, then the db meter and vu meter are identical. A vu meter can always be used as a db meter; however, a db meter can be used as a vu meter only when the audio output is steady. A vu meter, which is lightly damped, responds more readily to instantaneous audio peaks, producing more accurate peak readings. Some vu meters are calibrated to read percentage of modulation as well as volume units, when calibrated to the equipment with which they are used.

(*c*) RECEIVER SENSITIVITY (AUDIO OUTPUT) TESTS.—Receiver output power is measured, as part of a sensitivity test, to determine whether the receiver is performing according to the required sensitivity specifications. (The sensitivity is the value of signal voltage (in microvolts) fed to the antenna terminals that will produce a specified power output—usually 6 milliwatts—at the receiver output terminals with a signal-to-noise ratio of 10:1.) A simple way to check audio power output is to use an a-c voltmeter (either a copper-oxide-rectifier type or an electronic voltmeter) across a resistor of the correct value, as specified in the instruction manual. With the signal generator delivering an input voltage to the receiver antenna terminals, the voltmeter measures the output voltage across the resistor. The power output is then computed by using the formula $P = E^2/R$.

(3) LF TO VHF POWER MEASUREMENTS.—In this frequency range (30 kc to 300 mc) output power is conveniently measured by connecting, as shown in figure 2-32, a dummy antenna in conjunction with an r-f thermocouple-type current meter into the antenna output circuit. The dummy antenna has a particular impedance, which is specified in the instruction manual for the particular transmitter being tested, and should have the same general electrical characteristics as the actual antenna, except that it does not radiate energy. Specially constructed, noninductive resistors (usually glass or metal

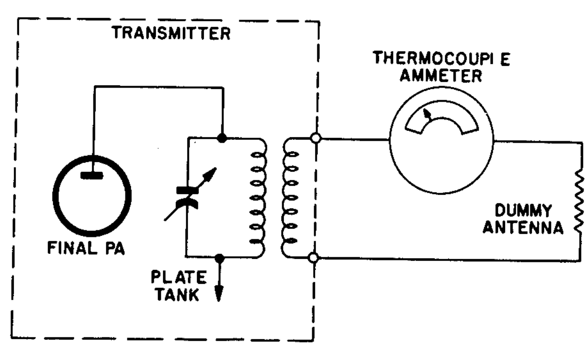


Figure 2-32. Measuring Power Output of Radio Transmitter

enclosed) are used in dummy antenna circuits; these resistors range in value from about 50 ohms to 600 ohms, in order to simulate values usually encountered in measurements of transmitting equipment. A thermocouple ammeter, similar to the type shown in figure 2-20, is then connected in series with the dummy antenna. After the transmitter is tuned according to the instruction manual, the reading of the r-f ammeter is noted and the output power is calculated. Since the load resistance is known, the power can be found by Ohm's law, $P = I^2R$.

Another method of measuring transmitter output power involves the use of a bank of incandescent lamps as a noninductive dummy antenna for the transmitter. A photographic illumination meter is arranged to measure the resulting brilliance of the lamp bank. The antenna connections are then removed from the lamp bank. A variable d-c (or a-c) power source is now used to light the bank of lamps to the same brilliance, and an ammeter-voltmeter (or wattmeter) is connected to determine the power required to bring the dummy antenna to that brilliance. This power is equal to the transmitter output. The impedance of the lamp bank should match the transmitter output impedance as closely as possible.

(4) UHF TO MICROWAVE POWER MEASUREMENTS.—At frequencies below the UHF portion of the spectrum it is ordinarily more convenient to measure power in terms of voltage, current, and impedance where these basic characteristics can be determined with a good degree of accuracy. However, at microwave frequencies the latter characteristics are difficult to determine, may differ greatly at slightly different points in a circuit, and are affected considerably by small changes in geometrical characteristics. As the frequency is increased the fundamental characteristics of a conductor—its a-c resistance, inductance, and distributed capacitance — become significant. Of particular importance with respect to power measurements is the resistance, because the resistance increases considerably as the frequency is increased, and this change is due to the increasing "skin effect." The explanation for skin effect is as follows: Each component of the current flowing through a conductor has magnetic lines of flux encircling it. By considering the distribution of flux lines in a cross section of the wire, it will be seen that the flux lines produced inside the wire by the current components in the center of the wire do not encircle the outer currents, while the flux lines produced by the components at the surface of the wire do encircle the currents at the center of the wire. Since the inductance of a given cross section of wire is proportional to the density of the flux lines in that area, and since the density of the lines is greater at the center of the wire, it is evident that the center has a much greater inductance than the surface, and therefore, more opposition to current flow. Hence the surface of the wire, where less inductance is present, has less resistance. Because current seeks the path of least resistance, it tends to travel along the surface of the wire. This, in effect, decreases the useful cross-section area of the wire, thus increasing the resistance of the conductor. The higher the frequency, the greater will be the skin effect and therefore the resistance of the conductor. It can be seen, then, that the direct measurement of power in the frequency range of UHF and higher frequencies assumes a degree of primary rather than secondary importance.

One of the most common methods of measuring power at the higher frequencies makes use of a bolometer, which is defined as a specially constructed element of resistive material that is temperature-sensitive. When r-f power is absorbed by this element, the resulting temperature rise is detected by measuring the change in bolometer resistance by means of an auxiliary bridge circuit. The most commonly used bolometers are called thermistors and barretters, which are described in detail and shown in test equipment circuitry in Section 3. Since the bolometer method adapts itself only to low-power measurements (a few microwatts to a fraction of a watt), sampling techniques involving the use of attenuating devices must be employed for high-power measurements. Some representative sampling devices are: the r-f probe, the directional coupler, the power divider, and the pickup antenna. These are described and their use discussed in Section 3.

In the following text, two basic bridge circuits utilizing a bolometer element are discussed. They are provided as an introduction to the measurement of microwave power, which is further expanded in Section 3 under the titles of TRANSMITTER TESTING — POWER MEASUREMENTS and RADAR TESTING — POWER MEASUREMENTS.

(*a*) THERMISTOR-BRIDGE. — A thermistor is a specially constructed resistor, usually a bead of nickel oxide (base) with manganese, uranium, or copper oxide (binders), which has a negative temperature coefficient. This means that as its temperature rises the resistance decreases and vice versa. A-C (or d-c) currents flowing through a thermistor, and r-f energy absorbed by it are factors that can cause a change in the resistance of the thermistor.

The thermistor bridge circuit shown in figure 2-33 is a basic bridge type circuit which depends for balance (null) upon the ratio of one pair of arms being equal to the ratio of the other pair of arms. Resistors R1, R2, and R3 have equal resistance values. The balance control is used to adjust the voltage applied to the bridge until the thermistor resistance, which depends upon the

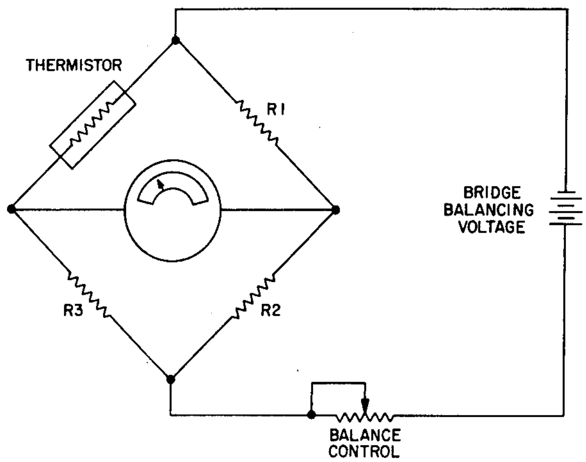


Figure 2-33. Basic Thermistor-Bridge Circuit

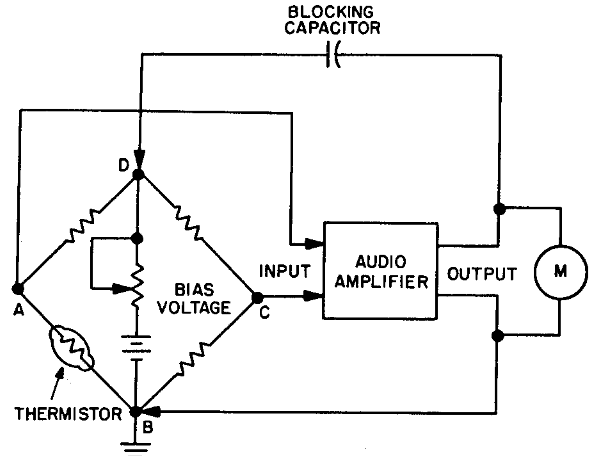


Figure 2-34. Self-Balancing Bridge

amount of d-c current flowing through it, becomes equal to the resistance in the other arms of the bridge. The bridge is now said to be balanced and is ready for making power measurements. Thermistor-bridge power meters use the D'Arsonval type of meter movement—usually 0 to 200 microamperes for maximum sensitivity (without series or shunt resistors).

The thermistor-bridge power meter is connected to measure UHF as outlined in the instruction manual for the particular equipment under test. A known portion of the r-f energy is fed to the thermistor-bridge power meter, striking the thermistor bead. The resistance of the thermistor decreases in proportion to the r-f energy absorbed, and the meter reads accordingly. From this reading, the power output is calculated.

Since thermistors change value as the temperature (external) changes, frequent zero settings are necessary. This disadvantage is largely overcome by utilizing additional thermistors and compensating networks. The resulting improved circuit is known as a compensated thermistor bridge and is discussed in detail in Section 3.

(*b*) SELF-BALANCING (A-C) BRIDGE. —The self-balancing type of bridge circuit utilized by some test equipments for the measurement of r-f power is shown in figure 2-34. Basically, the setup consists of a conventional audio amplifier, the output of which feeds one half of the bridge, shown as points A and C in the figure. The input to the audio amplifier is taken from the other half of the bridge at points A and C. With the thermistor element at room temperature, the bridge is unbalanced, and, in this condition, permits the coupling of energy to take place through the bridge at points BD to AC. This results in the system breaking into oscillation. However, as the oscillations increase in amplitude, the resistance of the thermistor element changes in such a manner as to bring the bridge more nearly into balance. If the amplification is made large, the amplitude of the oscillations will take whatever value is necessary to make the bridge almost, but not quite, balanced. A smaller amplitude than this will cause the bridge to be considerably unbalanced, resulting in a large input voltage to the amplifier and hence, increased output. At the same time, a slightly greater amplitude will bring the bridge into exact balance, allowing no coupling between input and output, and hence no oscillations. As connected into the circuit, meter M measures the amplitude of the oscillations. With no r-f power applied at points A and B, adjustment of the d-c bias voltage provides a means of setting meter M to full scale. The r-f power under test is now introduced into the thermistor and is dissipated by that element. This results in a reduction in the amount of power that the oscillations must supply to the thermistor to bring the bridge near a balanced condition. Therefore, by suitable calibration of meter M, the amount of r-f power dissipated by the thermistor element can now be indicated by the deflection of that meter.

2-7. FREQUENCY MEASUREMENT.

Frequency-measuring equipment and devices, particularly those used to determine radio frequencies, constitute a distinct class of test equipment, because of the important and critical nature of such measurements. The discussion to follow is concerned principally with the absorption wavemeter, the heterodyne frequency meter, and the counting type frequency meter. The requirement of precise calibration is extremely important in all frequency-measurement work. In order to provide accurate measurements, every type of frequency meter must be calibrated against frequency standards.

a. FREQUENCY STANDARDS. — Of considerable importance in measurements of frequency (or wavelength) are the standards against which

frequency meters (or wavemeters) are compared and calibrated. The absolute standard of frequency is the period of rotation of the earth (one cycle per day) as measured by astronomical observations. This function is performed in the United States by the U. S. Naval Observatory.

(1) FREQUENCY STANDARDS CLASSIFICATION.—More practical frequency standards for electronic testing are given below.

(*a*) FREQUENCY STANDARD. — Any oscillator of known frequency with adequate accuracy and stability for its intended application.

Note

Absorption Resonators continuously or intermittently driven in use are not truly frequency generators, but they may serve as low or high grade reference standards. It is often more convenient to refer to the instrument that determines frequency, as the Standard, rather than its generated output frequency.

(*b*) PRIMARY FREQUENCY STANDARD.—A Frequency Standard of proved frequency accuracy and long-term stability, determined by comparison with a standard interval of time.

(*c*) U. S. NATIONAL FREQUENCY STANDARD.—A Primary Frequency Standard maintained by the U. S. National Bureau of Standards.

(*d*) SECONDARY FREQUENCY STANDARD.—A highly accurate standard which has been calibrated against a Primary Frequency Standard.

A secondary frequency standard usually includes one or more divider stages with suitable harmonic generators and amplifiers. These oscillators usually operate in the frequency range between 25 and 1000 kc, and the fixed frequency of oscillation is accurately maintained by a simple temperature-controlled oven or compartment. The oscillator stage is usually semi-fixed, so that it cannot easily be moved or changed after proper initial adjustment. The accuracy of a secondary frequency standard is maintained only when periodic calibration checks are made against a primary standard, or against standard frequency transmissions of WWV and WWVH, which are broadcast continuously and monitored from the National Primary Frequency Standard that is maintained at the Bureau of Standards, Washington, D. C.

(2) U. S. NATIONAL BUREAU OF STANDARDS.—The Bureau of Ships Manual, Chapter 67, requires that all activities check their frequency meters for accuracy against the standard frequency transmissions of WWV and WWVH, and that a record of each check be made in the material log.

The National Bureau of Standards provides continuous broadcasts of standard frequencies and related services from Station WWV at Beltsville, Md., near Washington, D. C., and from station WWVH, at Maui, Territory of Hawaii. The following information is taken from the National Bureau of Standards' Letter Circular LC 1009 dated April 15, 1952.

(*a*) STANDARD RADIO FREQUENCIES.—To ensure reliable coverage of the United States and extensive coverage of other parts of the world, the radio stations provide the standard frequencies listed in Table 2-4.

TABLE 2-4. NBS CONTINUOUS BROADCASTS

STATION WWV	
FREQUENCY (MC)	**OUTPUT POWER (KW)**
2.5	0.7
5.0	8.0
10.0	9.0
15.0	9.0
20.0	8.5
25.0	0.1
STATION WWVH	
5	0.4
10	0.4
15	0.4

Note

The three broadcasts of station WWVH are interrupted for four minutes following each hour and half hour and for periods of 34 minutes each day beginning at 1900 GCT (Greenwich Civil Time). Also, during the week including the third Tuesday of each month the WWVH broadcasts are interrupted from 1900 to 2200 GCT, as follows: 5-mc broadcast on Tuesday, 10-mc broadcast on Wednesday, and 15-mc broadcast on Thursday.

(*b*) STANDARD AUDIO FREQUENCIES.—Two standard audio frequencies, 440 cps and 600 cps, are broadcast on all carrier frequencies. These audio frequencies are given alternately, starting with 600 cps on the hour for four minutes, interrupted one minute, followed by 440 cps for four minutes, and interrupted one minute. Each ten minute period is the same. The 440-cps signal is the standard musical pitch, A above middle C.

(*c*) STANDARD TIME INTERVALS.—The audio frequencies are interrupted for intervals of precisely one minute. They are resumed precisely on the hour and each five minutes thereafter. They are in agreement with the basic time service of the U. S. Naval Observatory, so that they mark accurately the hour and the successive five-minute periods.

Greenwich Civil (or Mean) Time (Universal Time) is announced in the telegraphic code each five minutes starting at 0000 (midnight). Time announcements are given with reference to the return of the audio frequencies.

A voice announcement of Eastern Standard Time follows each telegraphic code announcement from station WWV; this precedes and follows each telegraphic code announcement.

At intervals of precisely one second, a pulse of 0.005-second duration is transmitted on each carrier frequency. The pulse consists of five cycles, each of 0.001-second duration. No pulse is transmitted at the beginning of the last second of each minute.

(*d*) ACCURACY OF TRANSMISSIONS.—The frequencies transmitted from WWV and WWVH are accurate to within 2 parts in 10^8 (with reference to the mean solar second, 100-day interval), as determined by the U. S. Naval Observatory with a precision of better than 3 parts in 10^9. The time intervals transmitted are accurate to within $\pm$ 2 parts in $10^8 + 1$ microsecond.

b. USING WWV AND WWVH FOR CALIBRATION.—The extremely accurate signals of WWV and WWVH transmissions may be used for calibrating frequency standards such as the LM series frequency meters and the AN/USM-29 frequency meters. The accuracy of the LM series frequency meter depends upon the crystal oscillator which generates crystal check-points located at intervals on the dial. The AN/USM-29 frequency meter is directly controlled by a 100-kilocycle crystal within the equipment. Because the crystal is the controlling factor in these and similar types of frequency meters, crystal calibration will assure accuracy of the frequency standard. The crystal of an LM series frequency meter may be checked in the following manner.

(1) LM TEST PROCEDURE.—Connect the LM meter to be checked and its associated equipment as shown in figure 2-35. Tune the receiver to the 5- or 10-megacycle WWV transmission, using the receiver bfo if necessary for accurate dial setting. Operate the LM frequency meter under test with the CRYSTAL switch set to ON. If the 1000-kilocycle crystal of the LM is oscillating at the correct frequency, its output signal will zero-beat with the WWV signal. A low-pitched audio growl will indicate a frequency difference of a few hundred cycles. The LM-18 frequency meters have a small adjustable trimmer capacitor across the crystal which should be used to obtain a zero-beat with the WWV transmission. The purpose of the 1-megohm potentiometer (figure 2-35) is to attenuate the WWV signal to a suitable value to heterodyne with the crystal signal.

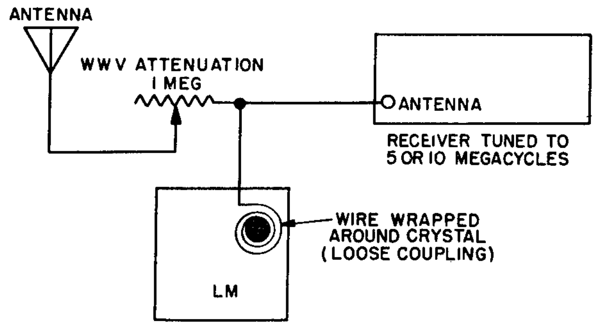


Figure 2-35. Block Diagram Showing Methods of Zero-Beating LM Crystal with WWV Transmission

(2) AN/USM-29 TEST PROCEDURE.—The AN/USM-29 frequency meters are calibrated in a similar manner. Connect the AN/USM-29 meter to be checked and its associated equipment as shown in figure 2-36. Allow the AN/USM-29 to warm up for at least 6 hours. Zero the interpolation oscillator so that the rate of 360-degree phase shift apparent in the pattern (the pattern "flop over") is less than once in three seconds. Tune the receiver, equipped with a signal-strength meter, to one of the WWV transmission frequencies. Adjust the r-f gain of the receiver so that the input of the WWV signal is approximately S5 on the S meter. Set the FR-47/U portion of the AN/USM-29 to the same frequency as that of the WWV transmission being used. Vary the position of the FR-47/U transmitting antenna in such a manner as to raise the signal-strength meter reading to about S8.

A definite swing of the receiver S meter pointer should now be observed, indicating the recurrence of the beat note between the WWV signal and that of the AN/USM-29 frequency meter. If a WWV transmission frequency of 2.5 megacycles

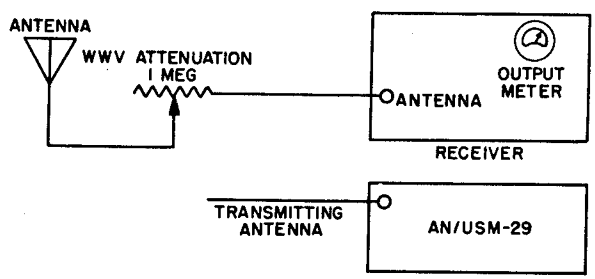


Figure 2-36. Block Diagram Showing Method of Zero-Beating Frequency Meter AN/USM-29 with WWV Transmission

is being used, the S meter pointer should not swing faster than two times per second. If this is not the case, the need for adjustment of the permeability-tuned inductor L102 is indicated. For the location of this tuning slug and more detailed information, refer to Instruction Book NavShips 91938, for Frequency Meter AN/USM-29.

c. AUDIO-FREQUENCY MEASUREMENT.—Audio frequencies can be measured in any of four principal ways: (1) by means of a bridge when conditions of balance are dependent upon frequency, (2) by comparison with a calibrated audio oscillator of other available frequency standard, (3) by use of a direct-reading frequency meter, and (4) by comparison with a known frequency using a cathode-ray oscilloscope (refer to paragraph 2-8.*b*.(1).

The accuracy of direct-reading audio-frequency meters compares favorably with that of bridge-type a-f measuring devices. Because of this fact, the direct-reading type of meter has largely superseded the bridge type. Direct-reading a-f meters can be utilized to measure the frequencies of either sine-wave or complex-waveform voltages.

(1) SINE-WAVE A-F METER.—The original form of a-f meter was essentially an a-c voltmeter which measured the a-c voltage across a resistor in series with a capacitor. The accuracy of this meter was dependent upon the strict sinusoidal shape of the applied waveform. Over a period of time, many refinements of the basic principle underlying this type of meter have been added. However, the use of this meter has largely been abandoned in favor of the pulse-integrating type of a-f meter.

(2) COMPLEX-WAVE A-F METER.—To measure the frequency of complex a-f waves (up to 50 kc), including short pulses of either positive or negative polarity, several effective circuits have been devised. One of the simpler circuits makes use of two gas triode tubes triggered alternately by the positive and negative components of the wave, which is applied to the triode grids through a phase-inverting transformer. The resulting current pulses which charge a capacitor are passed through a milliammeter. The meter current is independent of the amplitude of the applied signal, because gas triodes are strictly triggering devices and maintain a constant plate-to-cathode potential during their conducting periods. Therefore, the average value of the direct current is proportional to the number of pulses per second, and the meter, when properly calibrated, indicates the fundamental frequency of the input voltage.

d. RADIO-FREQUENCY MEASUREMENT.—The simplest method of determining the frequency of r-f oscillation is by means of an absorption (or reaction) wavemeter. When the wavemeter is loosely coupled to the tank circuit of an oscillator stage or transmitter circuit, the absorption wavemeter draws a small amount of energy, which is maximum only when the meter is tuned to the resonant frequency of the oscillator, or transmitter. A flashlight bulb, a milliammeter, or some other device which gives the greatest brilliance or the highest reading at the point of maximum energy absorption is used to indicate the resonant condition. The absorption wavemeter is extremely useful for checking the fundamental frequency of an oscillating circuit, the frequency of parasitic oscillations, and the frequency of harmonic oscillation. It is also practical for checking the neutralization of an amplifier, for detecting the presence of r-f energy in undesired parts of a chassis or equipment, and for determining radiated field strength in relative measurement terms.

More reliable meters for measuring radio frequencies are heterodyne frequency meters, which determine the frequency of an unknown r-f signal by matching the signal (or its harmonics) with a locally generated signal of the same or some harmonic frequency obtained from a calibrated, high-precision oscillator. Perfect matching is indicated by the absence of a beat note (zero beat). The zero-beat indicator in test equipment of this type is generally a pair of headphones.

(1) WAVEMETERS.—Wavemeters are of two basic types—reaction and absorption. Both types absorb part of the output power of the device whose frequency is to be measured. The reaction wavemeter absorbs very little power, and is therefore preferred for use when measuring frequencies in low-power equipment. An indication of resonance is supplied by the device under test (usually from an ammeter). The absorption wavemeter is more accurate than the reaction wavemeter and absorbs slightly more power from the device under test. Since it tends to load the equipment, its use is generally restricted to high-power devices. The indicator of resonance, usually an ammeter or lamp, is connected into the tank circuit of the wavemeter.

For making preliminary adjustments on transmitters and for general experimental work, the simple resonant-circuit wavemeter is a valuable tool. However, wavemeters cannot be relied on for accurate measurements, because they tend to detune self-excited oscillator circuits to which they are coupled. The brightest indication or highest reading normally indicates the fundamental frequency. Therefore, this type of meter is very useful for checking a transmitter to determine whether the oscillator is operating on the correct fundamental frequency.

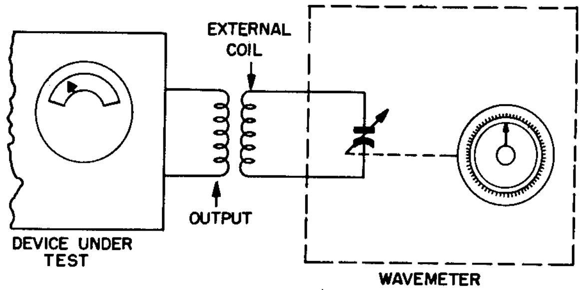


Figure 2-37. Circuit of Reaction Wavemeter

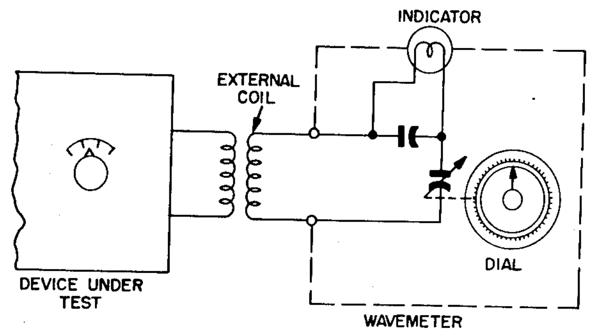


Figure 2-38. Circuit of Absorption Wavemeter

(*a*) REACTION TYPE.—The circuit of a reaction type wavemeter, containing a coil and a variable capacitor, is shown in figure 2-37. The coil, which is external to the wavemeter, is loosely coupled to the output of the circuit whose frequency is to be measured. The resonant frequency of the wavemeter is made equal to the frequency of the circuit under test by varying the capacitor. At this point the indicating device (usually an ammeter) shows either maximum or minimum, depending upon its circuit location. The scale, which is usually an accurately calibrated vernier dial, is then read and the frequency (or wavelength) is found by reference to a calibration curve or chart. When the wavemeter reaches resonant point (maximum loading effect), it is important that the coupling is reduced to the point which produces a barely usable indication. If the coupling is not reduced as specified, a sharp indication of resonance will not be obtained and a consequent error will be introduced.

(*b*) ABSORPTION TYPE.—The absorption type wavemeter, shown in figure 2-38, is basically the same as the reaction type described in the previous paragraph. An indicating device (lamp) and a fixed capacitor are used in the absorption type wavemeter to provide a self-contained indicating device. The fixed capacitor, across which is connected the indicating lamp, has a much greater capacitance than the variable. This large capacitance permits a voltage to be developed at resonance to light the lamp, and at the same time it has negligible effect on the resonant circuit because of its low reactance. When this type wavemeter is coupled into the circuit under test, care must be used as the resonant point is approached so that the lamp will not burn out. The dial should be rotated slowly, and as the lamp begins to glow the wavemeter coupling should be reduced. For greatest accuracy the wavemeter should be so coupled that maximum brilliance is only a faint glow.

(2) HETERODYNE FREQUENCY METER.—When a major naval operation is planned, surface ships, submarines, carrier-based planes, and land-based air-force units may be required to synchronize their separate movements by joint communications on frequencies on which absolute silence must be kept until contact with the enemy has been made. One important task is to accurately set radio receivers and transmitters on the frequencies assigned by the task-force communications officer. To accomplish this assignment, the technician uses a frequency meter of high accuracy (of which the Navy Models LR and LM series are representative). A type of meter that is suitable for use when great accuracy is required, as in the case just described, is the heterodyne frequency meter. This type of meter will be discussed in the following paragraphs.

(*a*) FUNDAMENTALS OF OPERATION.—The basic heterodyne meter, as shown

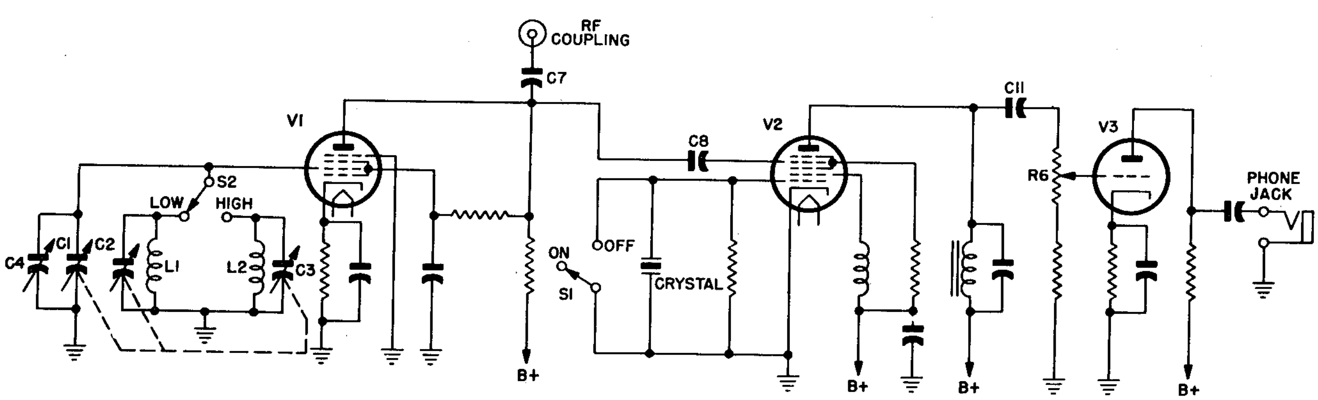


Figure 2-39. Simplified Schematic Diagram of a Typical Heterodyne Frequency Meter

in figure 2-39, consists of a calibrated variable oscillator (and associated circuits) which beats, or heterodynes, against the frequency to be measured. Coupling is arranged between the frequency meter and the output of the device under test. The calibrated oscillator is then tuned so that the difference between the oscillator frequency and the unknown frequency is in the audio range. This difference in frequency is known as the beat frequency and when detected and amplified it is audible in a headset. By further tuning of the calibrated oscillator it is possible to lower the difference frequency to a point (zero-beat frequency) at which no sound is heard. At this point the frequency of the calibrated oscillator is equal to the unknown frequency. After the zero-beat frequency is obtained, the dial reading (when properly interpolated) corresponds to the frequency under measurement.

(*b*) HETERODYNE-FREQUENCY-METER CALIBRATION. — Most heterodyne frequency meters contain a stable crystal oscillator which is used for calibrating the frequency of the variable oscillator. This crystal oscillator produces a number of harmonics which permits calibration of the test equipment at various frequencies. These points of calibration are called crystal check points, and the frequencies at which they occur are given (usually in colored type) in a calibration book, which is also used to interpolate the dial reading. Figure 2-40 shows a typical setup for calibrating a frequency meter. Assume that the calibration book shows a crystal check point at a frequency of 2000 kc. The dial setting of the meter is adjusted to correspond to the number given in the calibration book for 2000 kc. With the crystal switch thrown to the on position, the output of the variable oscillator beats with the output of the crystal oscillator, and, if there is a difference between the two frequencies, a beat note (usually in the audio range) is produced. In figure 2-40 the frequency of the beat note is 300 cycles, indicating that the variable oscillator is not tuned exactly to 2000 kc. The variable oscillator is adjusted to the exact frequency by means of a corrector knob, which is turned until zero beat is obtained.

(*c*) BASIC CIRCUIT OPERATION. — Figure 2-39 shows a simplified schematic diagram of a typical frequency meter. The circuit of tube V1 is the variable oscillator, the output of which beats against the unknown frequency entering by way of the external coupling. The electron-coupled oscillator of V1 has good stability under varying load conditions. Switch S2 permits operation on two frequency ranges. Capacitors C2 and C3 are variable and cover the entire low- and high-frequency ranges, respectively. Capacitor C1 changes the natural frequency of the oscillator on both ranges but to a lesser degree than C2 and C3. C1, C2, and C3 are ganged together and are varied by the front panel tuning knob. C4 is a trimmer capacitor, called the corrector, which is used to correct any frequency deviations of the oscillator during calibration.

The circuit containing V2 is the mixer stage, and serves also as a pentagrid converter when the variable oscillator is being calibrated. With switch S1 in the off position, the control grid of V2 is grounded and V2 functions as a mixer stage. The output of V1 is applied to the mixer through capacitor C8 along with the unknown frequency, which is fed through C7. For calibration of the meter, S1 is thrown to the on position and V2 becomes a pentagrid converter, with the crystal-oscillator section using the cathode and the two nearest grids, and the mixer section employing the remaining electrodes. The output of V2 is coupled by means of C11 to amplifier V3, and the output of this tube is fed to the headphones. Resistor R6 is variable potentiometer which controls the gain of V3.

(*d*) DIAL READING AND INTERPOLATION.—Figure 2-41 shows the dial of a typical heterodyne frequency meter. The dial setting as shown is read in the following manner: The long,

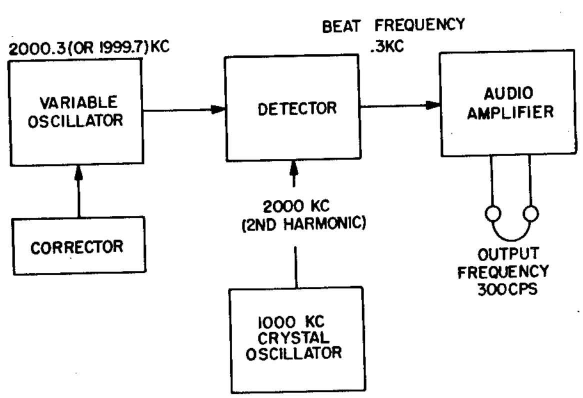


Figure 2-40. Typical Setup for Calibrating a Heterodyne Frequency Meter

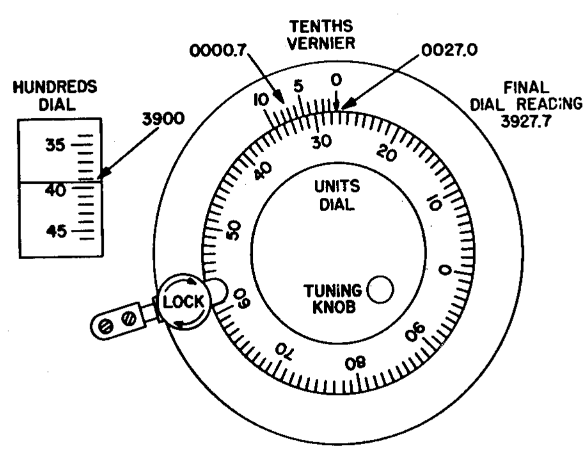


Figure 2-41. Dial of a Typical Heterodyne Frequency Meter

thin line marked on the window of the HUNDREDS dial indicates the approximate reading of the dial. Since it is situated between 3900 and 4000, the exact dial reading must be between these numbers. The reading on the UNITS dial is read directly below the arrow on the TENTHS vernier, and is between 27 and 28. To obtain the exact reading to the nearest tenth, the TENTHS vernier must be read. The TENTHS value is obtained by finding the line on its scale which coincides most closely with a line on the UNITS dial. The value of .7 coincides with 33 on the UNITS dial; therefore, the exact reading of the dial setting shown in figure 2-41 is 3900 + 27 + .7, or 3927.7. The frequency reading corresponding to this number must be obtained from the calibration book which is included with each frequency meter.

Whenever the observed dial setting falls between two consecutive dial settings listed in the calibration book, it is necessary to interpolate to find the corresponding exact frequency. The dial reading shown in figure 2-41 lies between the numbers 3925.5 and 3927.9, as taken from the calibration book, and the frequencies corresponding to these dial settings are 3669 kc and 3670 kc. The difference between the listed dial settings is the difference between the dial reading and the next higher listed dial settings, as the corresponding difference between the listed frequencies is the frequency difference between the unknown frequency and the next higher listed frequency. This is shown in the formula:

$$\frac{2.4}{.2} = \frac{1\text{ kc}}{x\text{ kc}}$$

These differences are easily found by employing a simple tabulation scheme as follows:

FREQUENCIES — DIAL SETTINGS

$$\text{diff. 1 kc}\left\{\begin{array}{l}\text{3669 kc}\\ \left.\begin{array}{l}\text{unknown kc}\\ \text{3670 kc}\end{array}\right\}\text{diff. x kc}\end{array}\right.\quad \left.\begin{array}{r}\text{3925.5 (listed)}\\ \text{diff. .2}\left\{\begin{array}{l}\text{3927.7 (dial reading)}\\ \text{3927.9 (listed)}\end{array}\right.\end{array}\right\}\text{diff. 2.4}$$

Solving for x in the formula above gives the frequency difference of .083 kc. This figure is then subtracted from the higher listed frequency, producing 3669.917 kc as the frequency corresponding to the dial reading. The last two significant figures can be discarded for all practical purposes.

(3) COUNTER-TYPE FREQUENCY METER.—The counter type of frequency meter is a high-speed electronic counter, with an accurate, crystal-controlled time base. This type of combination provides a frequency meter which automatically counts and displays the number of events (cycles) occurring in a precise time interval. The frequency meter itself does not generate any signal but merely counts the recurring pulses fed to it.

(*a*) BASIC CIRCUIT OPERATION.—The basic circuit consists of an input circuit, an electronic gate controlled by an oven type of crystal-controlled time-base circuit, and a series of electronic counting units.

Positive pulses of the signal to be measured are amplified, shaped, and then fed to an electronic gate. The gate is opened by a signal from the time-base circuit, remains open for an accurately controlled interval of time, and is then closed on a second signal from the time-base circuit. After the gate closes, the total number of events (cycles) counted is then displayed on the illuminated panels of the decade counting units.

When the counting type of frequency meter is to count higher frequencies, a crystal-controlled heterodyne unit is added to the basic circuit. The heterodyne unit consists of a 1-megacycle pulse generator and harmonic selector, a mixer, an output amplifier, a low-pass filter, and an output level meter. A single, rotary, front panel control is provided for selection of any harmonic of 1 megacycle, from the second to the forty-first. The selected harmonic is used as a reference frequency for injection into the mixer. Should the unknown frequency being measured be less than 1 megacycle, it will pass directly through the low-pass filter to the output amplifier and then to the electronic counting circuits.

Both the 1-megacycle pulse generator and the time-base generator are controlled by a single 1-megacycle crystal, so that only one adjustment is required to calibrate the entire counting-type frequency meter. In addition, the 1-megacycle crystal can be locked-in with a WWV signal, further increasing its accuracy. Various time bases and display times can be selected through front panel controls provided.

(*b*) ADVANTAGES AND LIMITATIONS.—The counter-type frequency meter permits the determination of frequency rapidly and without involved interpolation or the possibility of ambiguous results. The measurement of a large number of different frequencies in quick succession is also facilitated. The counter-type frequency meter is also independent of input waveform, since the input signal is eventually shaped to a series of pulses recurring at the same frequency as the input signal. By heterodyning the unknown frequency with a fixed frequency within the unit, the frequency range of the test equipment may be extended from its basic range

of about 100 kc to approximately 30 mc. The primary limitation of this type of frequency meter is that it cannot be used directly for receiver calibration, since it is a passive device, and therefore does not produce signals.

(4) GRID-DIP METER.—The grid-dip meter consists of an oscillator with a sensitive milliammeter connected in the grid circuit. When the tuned circuit of the grid-dip oscillator is placed in close proximity to another circuit tuned to the same frequency, power is absorbed from the grid-dip meter grid circuit. This condition is indicated as a dip by the meter connected in the grid circuit of the grid-dip meter. The looser the coupling employed to obtain this indication, the more accurately the grid-dip meter dial may be set. Because of the construction, size, and portability of the grid-dip meter, its dial cannot be calibrated very accurately. For precise frequency indication, the grid-dip meter should be heterodyned with a more accurate frequency standard. The grid-dip meter may be used as a wavemeter when the oscillator plate voltage is removed. For this use, the meter will indicate a maximum reading when resonance is reached. Refer to paragraph 3-6.*e.* for other grid-dip meter applications.

e. ULTRA-HIGH FREQUENCY MEASUREMENT. — When the ultra-high radio frequencies (300 to 3000 mc) are reached it is physically impossible to use the ordinary type of absorption wavemeter because of the small values of inductance and capacitance necessary for resonance at these higher frequencies. If the wavemeter type of frequency meter is to be used in this region of the r-f spectrum it is necessary to utilize either a resonant-cavity or a resonant-coaxial-line type of frequency meter. The resonant-cavity type of frequency meter, which contains a movable end plate and a micrometer screw arrangement, to adjust the cavity resonance, is more adaptable for measurements in the higher portion of the UHF region. The accuracy of this type of meter is comparable to that of the resonant coaxial type, which will be discussed more in detail in the text to follow.

A simpler and fairly accurate method of ultra-high-frequency measurement is by means of a Lecher-wire system, in which the wavelength of a signal is determined by direct measurement of the standing-wave patterns on a short section of a resonant transmission line.

(1) RESONANT-COAXIAL-LINE FREQUENCY METER.—Figure 2-42 shows a typical resonant-coaxial-line frequency meter. Energy is fed into the line by means of a small inductive coupling loop, and, in most cases, another coupling loop is provided so that an output is available to operate some form of indicator. In addition, the coupling loops may be made adjustable

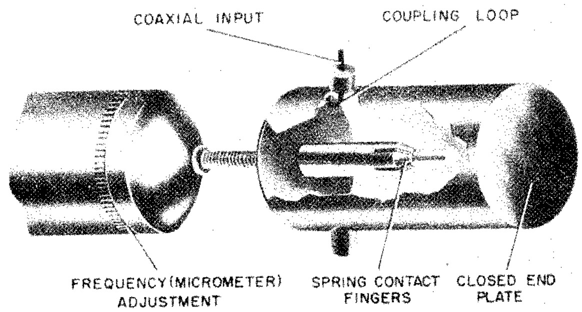


Figure 2-42. Resonant-Coaxial-Line Frequency Meter

to provide control over the degree of coupling. The resonant frequency is varied by changing the length of the sliding center conductor, which directly varies the distributed capacitance of the line. The length of the conductor is adjusted by means of a micrometer screw which is attached to the conductor. The conductor is positioned centrally and is contacted electrically by spring contact fingers. The micrometer screw may drive a dial that indicates frequency directly, or the micrometer readings may be easily converted to frequency by means of a chart.

Resonant-coaxial-line frequency meters operate as either transmission or reaction type indicators. In a meter of the transmission type, the energy whose frequency is to be measured is fed into one coupling loop, and the indicating device is connected to the other loop. With the circuit resonant, there is maximum transfer of energy and the indicator shows the greatest output signal. In a meter of the reaction type, the resonant circuit functions as an absorption device, so that at resonance the indicator shows a dip in the reading. When the latter type is used, only one coupling loop is necessary, because the indication of resonance is supplied by the device under test.

(2) LECHER-WIRE METHOD OF FREQUENCY MEASUREMENT.—The Lecher-wire system used for measuring frequency (shown in figure 2-43) is essentially a resonance device, which utilizes the direct measurement of the length of a radio wave (standing wave pattern) on a short section of a resonant transmission line. In a typical arrangement the section of transmission line actually consists of a "folder" wire

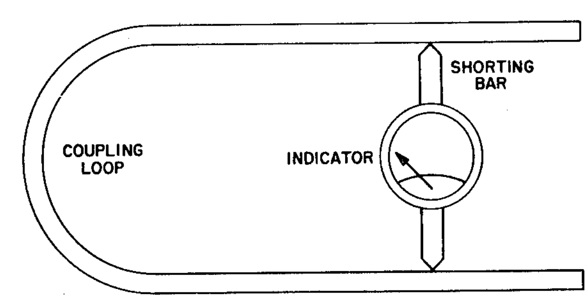


Figure 2-43. Lecher-Wire System for Ultra-High-Frequency Measurement

or bar, which constitutes the Lecher wire. The loop end is coupled to the source of frequency to be measured, and the two opposite ends are short-circuited by means of a shorting bar. In series with the shorting bar is a sensitive r-f thermocouple-type meter. As the position of the shorting bar is varied, a series of sharply defined positions corresponding to the maximum (or minimum) current indications of the meter are identified and located. Care should be taken to maintain the shorting bar at right angles to the Lecher wires. These positions coincide with the current peaks (or nodes) of the standing wave on the transmission line, and therefore any two consecutive positions are exactly one-half wavelength apart for the particular signal being measured. Accordingly, the wavelength of the unknown signal is obtained simply by measuring the distance in centimeters between any two such points. When the wavelength is known, the frequency of the unknown signal is determined by the equation:

$$\text{Frequency (mc)} = \frac{30{,}000}{\text{wavelength (cm)}}$$

2-8. WAVEFORM MEASUREMENT.

A waveform may be considered as a pictorial representation of a varying potential as related to time. By using a linear time base as a known function, an unknown waveform may be plotted and analyzed by using a system of coordinates. Such an analysis of waveforms provides information of great value in determining the characteristics of many electronic (and some mechanical) devices. The path of a signal of known amplitude and waveshape may be traced through an amplifier, and the gain and distortion characteristics of this amplifier may then be quickly and easily determined; or, if the amplifier is defective, the stage in which the signal path is interrupted may be isolated. The waveform of a signal may indicate the presence of harmonics or parasitic oscillations, or it may indicate how closely a device is following a desired cycle of operation. Upon the basis of these facts, it is apparent that there is an important need for a test equipment that can provide a pictorial presentation of a waveform at the instant of its occurrence in a circuit. The test equipment used for this purpose is the cathode-ray oscilloscope.

An oscilloscope incorporating only the basic circuits necessary for operation has been selected for discussion in the following paragraphs in order to facilitate explanation and to provide the technician with information on the minimum number of circuit components required to make a useful, though somewhat limited, test equipment. As the need for more accurate oscilloscope presentations develops, various circuit refinements and modifications are added to the basic oscilloscope. Present-day applications, especially pulse-voltage analysis, require that the oscilloscope bandpass be very broad so as to faithfully reproduce the waveforms encountered in present-day circuitry and also that both the signal and time axes be calibrated. The latter need resulted in the development of the synchroscope, which is discussed later under the heading of SPECIAL OSCILLOSCOPE CIRCUITS.

a. THE OSCILLOSCOPE.—The cathode-ray oscilloscope provides a visual representation of one electrical quantity as a function of another on the screen of a cathode-ray tube. The usefulness of the oscilloscope lies in its ability to portray graphically and instantaneously the fluctuating circuit conditions. Operation of the oscilloscope is based upon the formation and control of a beam of electrons for the purpose of producing a visible trace on a fluorescent screen. Since the electron beam has negligible inertia, the cathode-ray tube responds to much higher frequencies than any other electrical indicating device. The principal components of a basic oscilloscope (figure 2-44) include a cathode-ray tube; a sweep (sawtooth) oscillator; deflection amplifiers (horizontal and vertical); and suitable controls, switches, and input receptacles for proper operation of the test equipment.

(1) CATHODE-RAY TUBE.—The heart of an oscilloscope is the cathode-ray tube. This is a special type of electron tube (see figure 2-45) in which electrons emitted by a heated cathode are focused and accelerated to form a narrow beam having high velocity. This beam is then controlled in direction and allowed to strike a fluorescent screen, whereupon light is emitted at the point of impact and produces a visual indication of the beam position. The electronic process of forming, focusing, accelerating, controlling, and deflecting the electron beam is accomplished by the following principal elements of the cathode-ray tube: the electron gun consisting of a heated cathode, a grid, a focusing anode, and an accelerating anode; a deflection system, for controlling the direction of the beam emanating from the electron gun; a fluorescent screen, for visually indicating the movement imparted to the electron beam; and an evacuated glass bulb, which contains all of the above elements of the cathode-ray tube. Partially covering the inside of the glass bulb is an aquadag (graphite) coating which provides a return path for electrons and at the same time serves to shield the electron beam electrostatically.

(*a*) THE ELECTRON GUN.—The electron gun, shown in block form in figure 2-44 (expanded in figure 2-45), provides a concentrated beam of high-velocity electrons. The cathode is an oxide coated metal cylinder which, when properly heated, emits electrons. These electrons are

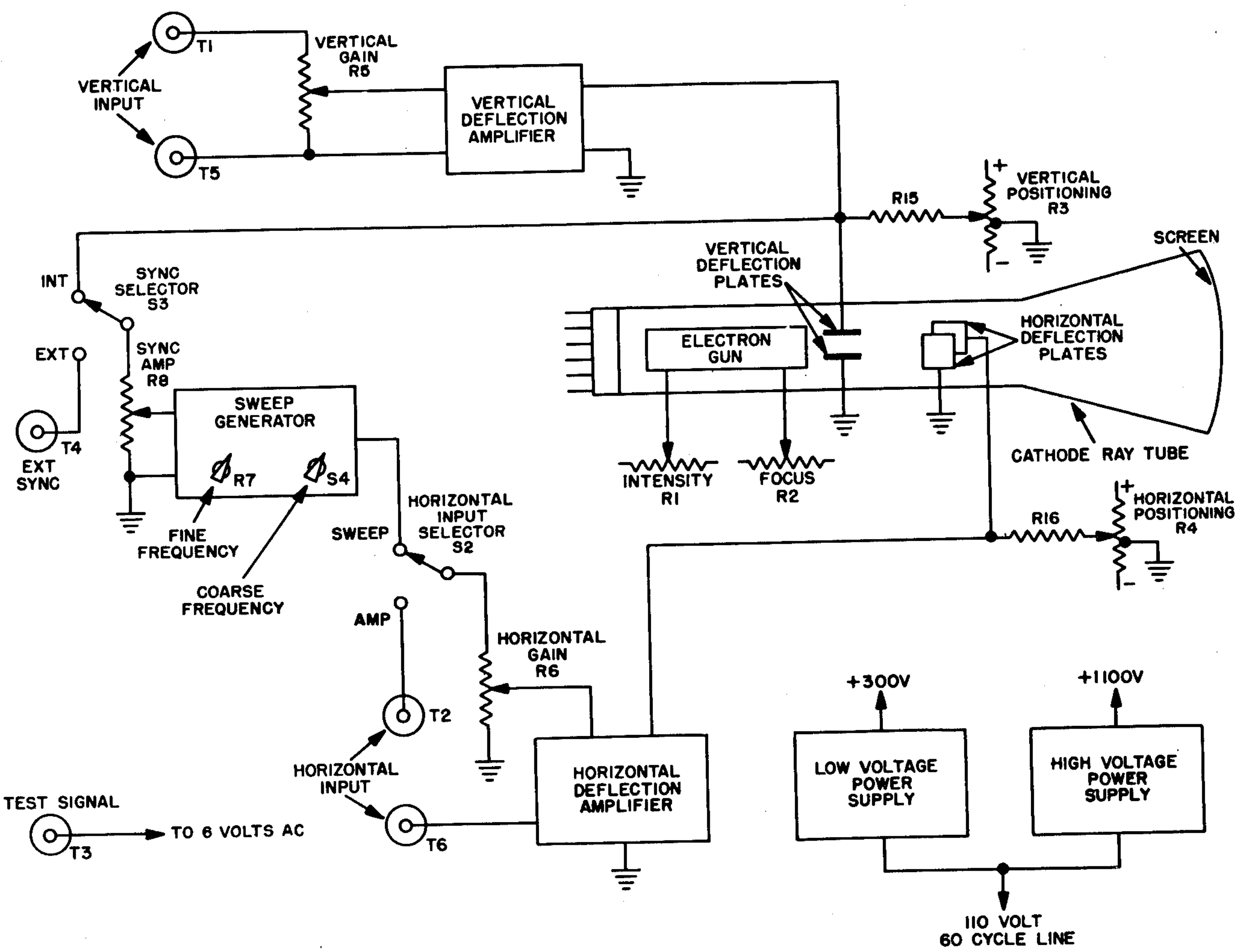


Figure 2-44. ***Block Diagram of a Basic Cathode-Ray Oscilloscope***

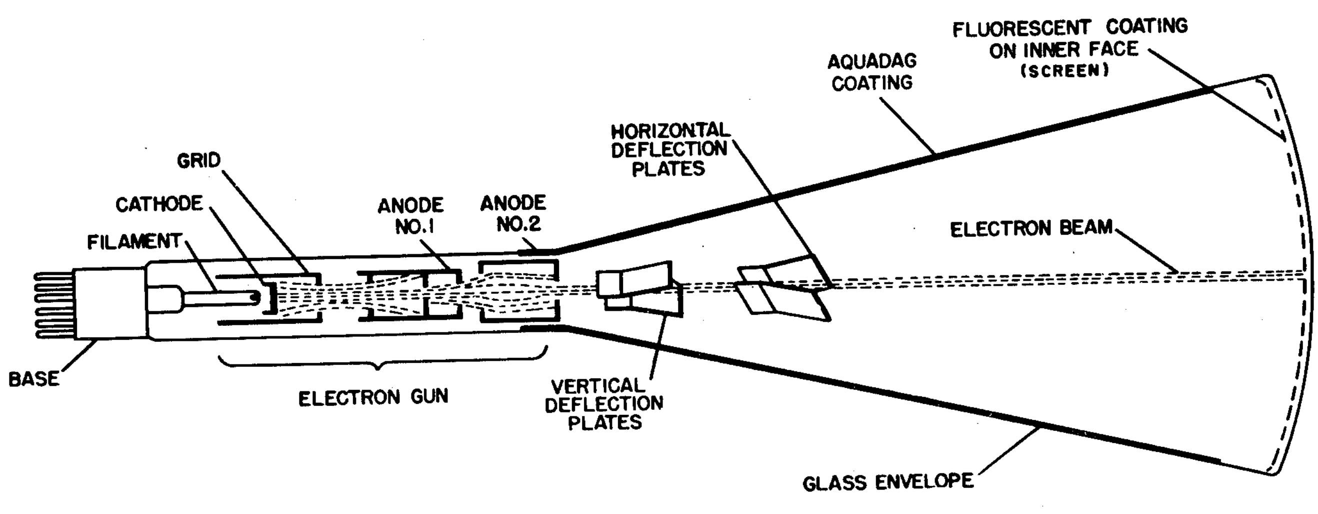


Figure 2-45. ***Cathode-Ray Tube***

attracted toward the accelerating and focusing anodes because of their high positive potential in relation to the cathode. In order to reach these anodes, however, the electrons are forced to pass through a control grid (a cylindrical piece of metal, closed at one end except for a tiny circular opening), which concentrates the electrons and starts the formation of a beam. Electrons leaving the grid aperture are strongly attracted by the positive charge on the focusing (anode No. 1) and accelerating (anode No. 2) anodes, which are cylindrical in shape and have small openings to permit beam passage. Between these two anodes an electrostatic field exists in the direction shown by the dotted lines in figure 2-45. Here the electrons move in a direction that is the resultant of their forward motion and of the electrostatic forces exerted which cause them to converge into a more concentrated beam. Since the electrons are now moving faster because of their attraction to the high positive potential of anode No. 2, the tendency to continue as a beam is greater than the tendency to diverge and follow the electrostatic lines of force. Thus, the electrostatic field existing between the first and second anodes serves as an electron lens, which focuses the electrons in somewhat the same manner as a double convex lens focuses a beam of light. However, the electron lens differs from the optical lens in that its focal length can be changed by simply changing the ratio of potentials between the first and second anodes. This ratio is changed by varying the potential on anode No. 1 by means of the FOCUS CONTROL, R2 (figure 2-44), which is a potentiometer located on the front panel of the oscilloscope. The potential on the second, or accelerating, anode remains constant. The intensity of the beam (number of electrons comprising the beam) is varied by potentiometer R1 (INTENSITY CONTROL), which changes the grid potential with respect to the cathode, thus permitting more or fewer electrons to flow. Because the potentials applied to the grid and both anodes are taken from a common voltage-divider network, any change made in the setting of the intensity control will require a compensating change in the setting of the focus control, and vice versa.

(*b*) ELECTROSTATIC DEFLECTION SYSTEM.—After the emitted electrons have been accelerated and focused to form a high-velocity beam, the electrons continue their travel toward the viewing screen until they strike the screen, which causes the screen to fluoresce, or give off light, within the region bombarded, thus forming a spot of light at or near the center of the tube. Other areas of the tube screen may be similarly activated by deflecting the beam from its normal path. The beam may be made to follow a curved path by either electrostatic or electromagnetic means. The electrostatic system is the predominant method for oscilloscopes.

Electrostatic beam deflection is accomplished through the use of two pairs of parallel plates that straddle the path of the beam. The second pair is oriented so that it is perpendicular to the first; thus, the electrons must pass between the plates of each set of deflection plates (see figure 2-45). If no electric field exists between the plates of either pair, the beam will follow its normal straight-line path, and the resulting spot will be at or near the center of the screen. A voltage potential applied to one set of plates will cause the beam to bend toward the plate that has the positive potential and away from the plate that has the negative potential. Deflection of the beam occurs virtually instantaneously, since it possesses an infinitesimal mass, and the bending is in direct relationship with the amplitude of the voltage applied to the plates. The second pair of plates influences the beam in the same manner, except that the bending occurs in a plane perpendicular to the first. The plates located nearest the gun structure are generally designated as the y-axis deflection plates; those nearest the screen are the x-axis plates. A voltage that is variable and recurrent with time, when applied to either set of plates, will cause the spot to move back and forth across the screen along a straight line. The movement of the spot across the screen will appear as a solid line when its cyclic rate exceeds the persistence of human vision or the persistence of the phosphor material forming the screen.

1. RESULTANT MOTION OF ELECTRON BEAM.—Nearly all applications of electrostatic-type cathode-ray tubes require that each pair of deflection plates acts upon the beam independently and simultaneously to produce a motion of the spot along the resultant of those forces exerted by each set of deflection plates. In this case the elecron beam is continually acted upon by two forces which are at right angles to each other. Figure 2-46 illustrates the resultant motion produced by independent deflection voltages that are applied simultaneously to the x and y

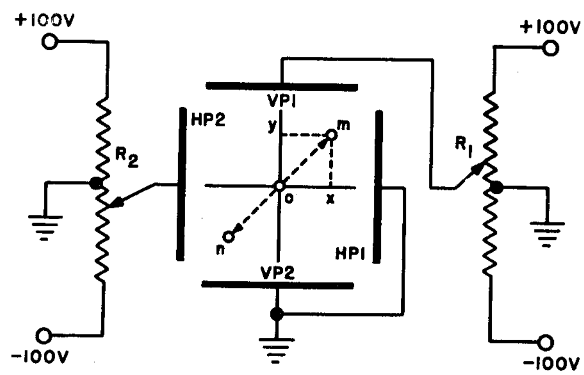


Figure 2-46. Resultant Motion of Electron Beam

axes. When the sliders of potentiometers R1 and R2 are at ground potential, all four deflection plates are at ground potential and the spot appears at 0 on the screen. If the slider on R2 is moved in a negative direction, horizontal-deflection plate HP2 becomes negative with respect to HP1, and the electron beam is repelled by the negative voltage on HP2. Under the action of this repulsion, the spot moves to point x on the screen. If the slider on R1 is moved in the positive direction, the vertical-deflection plate VP1 becomes positive with respect to VP2, causing the beam to be attracted from point x to point m. Now, if the above adjustments of R1 and R2 are made simultaneously and at the same rate, the resultant of the electrostatic forces exerted along the x and y axes will cause the spot to move to point m along the line, om. If the same control setup is turned in the other direction, the spot moves along the new resultant, on. Thus it is demonstrated that when two voltages, whether they be steady state or of a variable nature, are applied simultaneously, one to each pair of deflection plates, the position of the spot at any instant is proportional to the resultant of the simultaneous forces exerted upon the beam at that instant.

2. POSITIONING (CENTERING) CONTROLS.—Since structural imperfections in the manufacture of cathode-ray tubes may cause the beam to strike at some point other than the center of the screen when no signals are applied, it is necessary to provide some means of positioning the beam. This is usually done by applying small d-c potentials to the deflection plates by means of potentiometers similar to those in the circuit described in the above paragraph (figure 2-46). Centering, or positioning, controls are also useful whenever the enlargement of a waveform to permit examination of minute characteristics is so great that the portion of interest moves off the cathode-ray-tube screen; in such cases the centering controls may be used to change the position of the waveform so that the desired portion is visible.

3. DEFLECTION SENSITIVITY. — The distance that the spot may be moved upon the viewing screen in either the horizontal or the vertical direction by a potential of one volt applied to the deflection plates defines the deflection sensitivity for the axis under consideration. This is usually given by the manufacturer, as one of the cathode-ray tube's characteristics, in millimeters per volt (d-c). The most accurate way of measuring deflection sensitivity is to apply a known d-c potential directly to the deflection plates and to measure the distance that the spot moves. This distance, in millimeters, divided by the voltage applied is the deflection sensitivity for that pair of deflection plates (expressed in mm/volt). Most cathode-ray tubes have sensitivities of less than 1 mm/volt.

Another way of expressing the ability of an applied voltage to cause beam deflection is called the deflection factor, which is defined as the voltage required on a pair of deflection plates to produce unit deflection of the spot and is usually expressed as d-c (or r-m-s) volts per inch. If a tube has a deflection factor of 60 volts (dc) per inch, it should be understood that for every 60 volts applied to the deflection plates the electron spot moves a total distance on the screen of one inch; hence, 120 volts, dc, would displace the spot 2 inches. When d-c voltage is applied to the deflection plates, the electron beam remains displaced from the center of the screen for the period that the voltage is applied; and only a spot, which is displaced from the center of the screen, is visible.

If an a-c voltage is applied to one pair of the deflection plates, the spot is never stationary on the screen of the scope, because the instantaneous value of voltage is constantly changing. As stated above, the deflection of the beam is at all times proportional to the voltage on the deflection plates. Therefore, the beam deflection constantly changes in proportion to the instantaneous value of the applied voltage. As a result, the electron beam scans the screen in such a manner as to produce a straight luminous line, the length of which is determined by the peak-to-peak value of the voltage. It can be seen in figure 2-47 that, when an a-c voltage is applied to the vertical-deflection plates, the electron beam is deflected upward and downward from its rest position by equal amounts. Assume that the vertical-deflection system shown in figure 2-47 has a deflection factor of 40 volts (dc) per inch and that the sine-wave voltage applied to the plates has a peak-to-peak value of 40 volts. Under these conditions, the upward and the downward deflection will each be ½ inch, producing a vertical line one inch long. The spot retraces this path at the frequency of the applied signal.

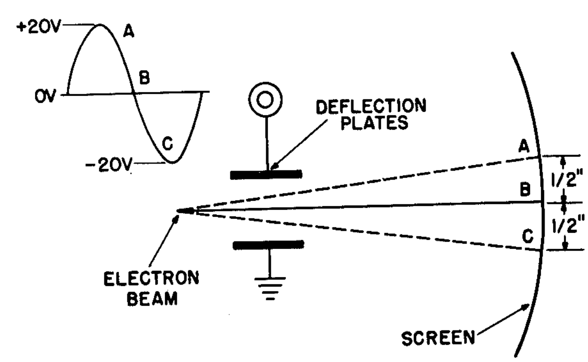


Figure 2-47. Diagram Illustrating Deflection Sensitivity

The x and y deflection sensitivity for cathode-ray tubes employing electrostatic systems are not equal—the vertical, or y plates, generally have the greater sensitivity. The inequality results from the differences in their positions in relation to the viewing screen, because it is not a practical design to mount both sets of plates at a common distance from the screen. Many compromises must be made in designing a cathode-ray tube. Therefore, the most desirable characteristics for a particular application are chosen. For example, if the ultimate in deflection sensitivity is essential, then (1) the tube must be long, (2) the second-anode potential must be kept low, and (3) the effective spacing of the deflection plates must be small. If the tube must be short, or if the anode voltage must be kept high for purposes of best spot size and a high brilliance, the sensitivity will of necessity be reduced. A method often employed for increasing deflection sensitivity is to increase the time during which the deflection potentials may act upon the beam and also to decrease the spacing between plates. This can be done effectively by installing long, closely spaced plates that bend away from the deflection path so as to permit a wide angle of deflection without interception of the beam by the plates. By this method the sensitivity can be substantially increased over that obtained with flat, parallel plates.

(*c*) FLUORESCENT SCREEN.—In order to convert the energy of the electron beam into visible light, that area where the beam strikes (labeled screen in figure 2-45) is coated with a phosphor chemical which, when bombarded by electrons, has the property of emitting light. This property is known as fluorescence. The intensity of the spot on the screen depends upon two factors—the speed of the electrons in the beam, and the number of electrons that strike the screen at a given point per unit of time. The amount of light per unit area which the phosphor is capable of emitting is limited, and once the maximum has been reached, any further increase in the electron bombardment has no further effect on the intensity of the light. In practical cases, the intensity is controlled by varying the number of electrons that are allowed to reach the screen. All fluorescent materials have some afterglow, which varies with the screen material and with the amount of energy expended to cause the emission of light. The length of time required for the light output to diminish by a given amount after excitation has ceased is defined as the persistence of the screen coating. The general classification of screen materials are in terms of long, medium, or short persistence. Various phosphors are used in oscilloscope work, each for specific applications. White and blue-white phophors of short and very short persistence are used where photographic records are taken of screen patterns. For general service work where visual observation is most important, a green phosphor having medium persistence is used. In viewing a line or pattern that is traced by a moving spot of light, the persistence of human vision, as well as that of the screen material, plays an important part. When the pattern is retraced at a rate of 16 times or more a second, the persistence of the eye retains the image from the previous sweep, and therefore the spot in its movement is no longer distinguishable as a spot and the path traveled appears as a continuous illuminated line. In cases of long-persistence phosphor materials, the persistence of the screen rather than that of the eye will govern, and the scanning rate, to produce a solid line, will be substantially lower.

CAUTION

Do not advance the INTENSITY control of an oscilloscope to a position which causes an excessively bright spot to appear on the fluorescent screen. A very bright spot may burn the screen and decrease the life of the cathode-ray tube. Also, for the same reason, never permit a sharply focused spot of high intensity to remain stationary for any length of time.

(*d*) AQUADAG COATING.—As previously described, the fluorescent screen of a cathode-ray tube is bombarded by a beam of electrons. If these electrons were allowed to accumulate upon the screen, the screen would soon acquire a negative charge that would effectively repel and disperse the electron beam, thus blocking the tube in its primary function. This, however, does not occur, because the beam, upon striking the screen, dislodges electrons from its surface (a process known as secondary emission). These dislodged electrons are attracted to positively charged tube elements, whereupon they are returned to the power supply. When the number of secondary electrons conducted away from the screen equals the number of electrons that return to, or are delivered to the screen, there is no accumulation of charge. Present-day cathode-ray tubes have a coating of graphite painted upon the inner glass surfaces but not connected with the screen. The functions of this coating are (1) to collect and return secondary electrons to the power supply, (2) to serve as an electrostatic shield against external electric fields, and (3) in some tube types to act in addition as an accelerating anode.

(2) POWER SUPPLIES.—If the oscilloscope is to function as a complete unit, both high-voltage and low-voltage power supplies are necessary. The output voltage of the high-voltage power supply is usually over 1000 volts, dc, depending upon the size of the cathode-ray tube, and

the output voltage of the low-voltage power supply is usually 300 volts, dc. The high-voltage power supply is necessary to operate the cathode-ray tube, and the low-voltage power supply provides the necessary voltages for the associated circuits and components.

Since the current needed to operate the cathode-ray tube is very small, an elaborate filter network is not required for the high-voltage power supply—usually a simple R-C network is adequate. Figure 2-50 shows the over-all schematic diagram of a basic oscilloscope. Half-wave rectification is utilized, providing an economical high-voltage output and also reducing the size and weight of the instrument (only one-half the number of secondary turns is required). A voltage divider, which includes the FOCUS and INTENSITY controls, provides the necessary voltages for the various cathode-ray tube electrodes. The high-voltage output is negative (approximately—1100 volts). This negative high voltage permits cathode-ray-tube operation with second anode and deflection plates at ground potential, which of itself is a safety factor.

Both the low-voltage and high-voltage power supplies utilize a common secondary on the power transformer. This permits a saving in copper as well as space, because a part of the low-voltage secondary is used to provide some of the high-voltage output. Full-wave rectification and a pi-type filter are used, thus ensuring good regulation and very low ripple voltage. The low-voltage power supply is of the conventional type (output approximately 300 volts) usually found in receivers.

(3) VERTICAL AND HORIZONTAL AMPLIFIERS.—The deflection system of a cathode-ray tube is relatively insensitive, requiring voltages on the order of several hundred volts for full-scale deflection. Therefore, it is necessary to utilize amplifiers to increase the amplitudes of the voltages for both the vertical and horizontal plates, so that test signals of low amplitudes may be effectively presented. When an amplifier is used between the signal source and the deflection plates, the signal is faithfully reproduced only if the limitations of the amplifier are not exceeded. These limitations include frequency discrimination (in the amplifier and also in the input attenuator circuit), phase distortion, and the maximum allowable input voltages (both dc and peak ac). The frequency response is an inherent characteristic of the grid and plate circuits of the amplifiers. However, the gain control enters into this response characteristic because of the effects of the variable distributed capacitance of the rotor of a high-resistance potentiometer (depending on its setting) at the higher frequencies. Phase distortion is also a function of the attenuator control for the same reason. The maximum input voltage is limited by the input coupling capacitors and by the dynamic range of the amplifier. A very important consideration in choosing an oscilloscope is the frequency-response characteristic of the vertical amplifier. Many applications of the oscilloscope require the observation of pulses, square waves, and other nonsinusoidal waveforms. Therefore, not only must the sinusoidal response be uniform, but also the transient response must permit undistorted amplification of irregular wave shapes.

The amplifier discussion thus far has been restricted largely to the vertical axis. Similarly, these considerations apply to the horizontal amplifier. For most oscilloscope applications, the signal applied to the horizontal deflection plates provides for the movement of the spot at a uniform rate with respect to time. Such a signal provides the time axis along which is plotted the unknown variable voltage. Without going into a detailed discussion of the generator which supplies the horizontal voltage, it will suffice to say at this time that the waveform of this time axis deflection voltage usually takes the form of a sawtooth, and is therefore rich in harmonic content. Since this sawtooth voltage is amplified by the horizontal amplifier, the frequency and phase characteristics of that amplifier should permit undistorted amplification of sinusoidal signals of frequencies extending both far above and below the sawtooth recurrence rates. The sawtooth frequency range extends from a few cycles per second to more than 50,000 cycles per second, so that quite stringent requirements are imposed upon the frequency-response characteristics of the amplifier. The frequency response of both amplifiers in the basic oscilloscope shown in figure 2-44 is from five to 100,000 cycles per second (sinusoidal). The manufacturer's maximum allowable a-c voltage input to either amplifier should not be exceeded.

(*a*) AMPLIFIER MODIFICATIONS.—From the above discussion it should be evident that the basic oscilloscope is limited principally because of the relatively poor frequency-response characteristics of the vertical and horizontal amplifiers. Modern oscilloscopes using improved amplifier circuits have much better frequency-response characteristics, and incorporate many circuit refinements.

1. GENERAL-PURPOSE OSCILLOSCOPE.—Oscilloscope OS-8/U is a good example of a general-purpose oscilloscope. A few of the characteristics of this test equipment which make it an improvement over the basic oscilloscope are: Vertical amplifier operates over a frequency range of 5 cps to 2 mc with a sensitivity of .1 volt (rms) per inch; direct-connected d-c vertical amplifiers operate from a frequency of zero to

approximately 1000 cps with a sensitivity of .4 volt (dc) per inch; horizontal amplifiers operate over a frequency range of 25 cps to 100 kc with a sensitivity of .1 volt (rms) per inch. For more detailed information on this general-purpose oscilloscope, consult the instruction book for Oscilloscope OS-8/U (NAVSHIPS 91272).

(4) SWEEP (LINEAR TIME BASE) GENERATOR. — When analyzing and interpreting any waveform on the screen of a cathode-ray tube, it should be borne in mind that the unknown voltage is always plotted as a function of another voltage, whose characteristics are known. In most oscilloscope applications, the horizontal axis is the known function, the characteristics of which are usually linear with respect to time. The conventional form of sweep voltage is the sawtooth waveform, which, when applied to the horizontal-deflection plates of the cathode-ray tube, produces a horizontal movement of the electron beam that is a direct measure of time as the spot moves from left to right. In order that time may always be indicated from left to right, the spot is returned to the left as quickly as possible at the completion of each sweep, so that time lost from the sweeping cycle is kept to a minimum. The time required in switching the beam is known as flyback time (see figure 2-48). When the rate or frequency of the sweeping sawtooth is adjusted to synchronism with the unknown signal applied to the vertical plates, the time variation or waveform of that signal is traced upon the cathode-ray tube. The sawtooth sweep voltage is produced by circuitry which is included as a part of the oscilloscope and is designated as the sweep generator. The sweep (sawtooth) generator, which is shown in figure 2-50 as tube V4 and associated circuitry, is based on the fundamental principle of charging a capacitor through a resistance from a constant source of potential to obtain an exponential charging wave (refer to figure 2-48) that is suitably linear for the time-base application. After charging to a predetermined level, the capacitor is quickly discharged, and the entire process is repeated at a frequency which is determined by the time constant of the R-C circuit.

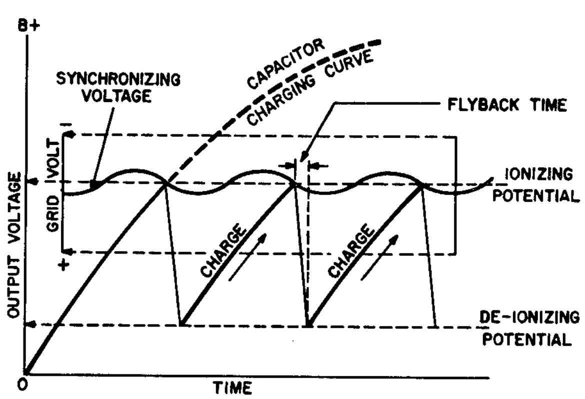


Figure 2-48. Action of Thyratron in Generating Sawtooth Waveforms

Tube V4 (figure 2-50) is a gas-filled triode (also known as a thyratron) which has a firing (ionization) potential determined by the grid and plate voltages. The negative grid voltage is supplied by cathode resistor R24 and dropping resistor R25. The plate voltage of V4 is determined by the amplitude of the sawtooth waveform required by the horizontal amplifier to produce adequate deflection. The recurrence rate of the sawtooth waveform is determined by the time constant (RC) of the plate circuit. This R-C circuit is made up of fixed resistor R26, variable resistor R7 (FINE FREQUENCY control), and a bank of capacitors, any one of which can be selected by switch S4 (COARSE FREQUENCY control). Use of a thyratron as the generator of sawtooth waveform, as compared with the similar use of a diode (neon tube), results in more stable operation of the sweep-generator circuit, because the addition of a grid permits more rigid control of the action of the gas-filled tube. Another advantage of the thyratron is that the grid electrode can be used to synchronize (harmonically or subharmonically) the sweep voltage with the voltage under test, thus preventing motion of the pattern on the screen. For example, in figure 2-50, if no synchronizing voltage is applied to the grid of the thyratron, the sweep generator becomes uncontrolled and operates in a free-running condition, i.e., its frequency governed solely by the R-C time constant of the circuit. If the sweep is not precisely in step with the voltage under test, the resulting pattern will be a moving pattern, and unless moving very slowly will be unintelligible. A method of locking the sweep generator to the frequency of the test signal is to inject a portion of the test signal upon the grid of the sweep thyratron; by this means the operation of the sweep generator is locked in step with the frequency of the input test voltage. Figure 2-50 shows that the synchronizing voltage is taken from the plate of tube V2, of the vertical amplifier, and is fed by means of switch S3 through capacitor C12, potentiometer R8, and resistor R23 to the grid of the thyratron. R8 (SYNC. control) is a potentiometer used to vary the amplitude of the applied synchronizing voltage.

(5) SPECIAL OSCILLOSCOPE (SYNCHROSCOPE) CIRCUITS.—Oscilloscopes designed for the analysis of pulse waveforms are calibrated in terms of time and voltage for the horizontal and vertical axes, respectively. Voltage calibrations are conducted by means of an attenuator at the input of the vertical amplifier and by a signal-generator circuit that produces a known level, or controlled levels of voltage which may be used for reference. The horizontal, or

time, axis is marked for selected intervals of time by precisely spaced pulses that produce either vertical lines, or if injected into the cathode or grid circuit of the cathode-ray tube, cause intensification or de-intensification of the trace at given time intervals. For a detailed description of the synchroscope, which is widely used in radar testing, refer to Section 3, paragraph 3-9.*b.*(2) (*a*) *4*.

(a) CALIBRATION GENERATOR.—The calibration generator uses a gas-filled VR-type voltage-regulator tube in conjunction with an intermittently operated relay to provide a continuous square-wave output of relatively low frequency (approximately 100 cycles) and of controllable amplitude (0.1 volt to 1 volt). Whenever the multiplier switch (shown in block diagram, figure 2-49) is turned to the calibration position, the chosen calibrating voltage is impressed on the signal input of the vertical amplifying system, so that the deflection per volt at this point can be determined for any setting of the gain control. Since this point of calibration is inside the oscilloscope at the output of the multiplier, the voltage of the signal at this point must be multiplied by the ratio of voltage increase back to the signal input. This ratio is a fixed

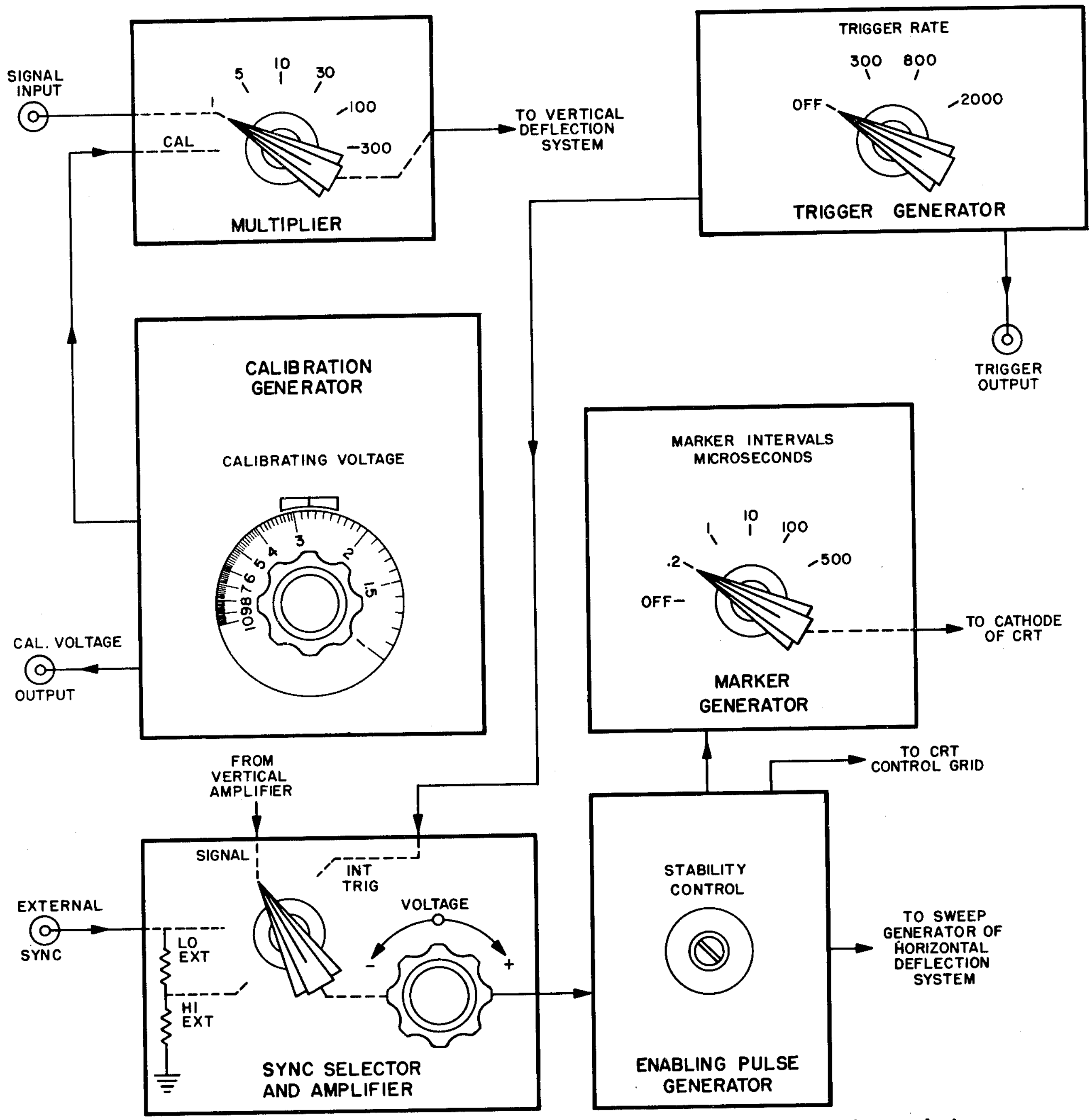


Figure 2-49. ***Block Diagram of Special Oscilloscope Circuits Used for Pulse Analysis***

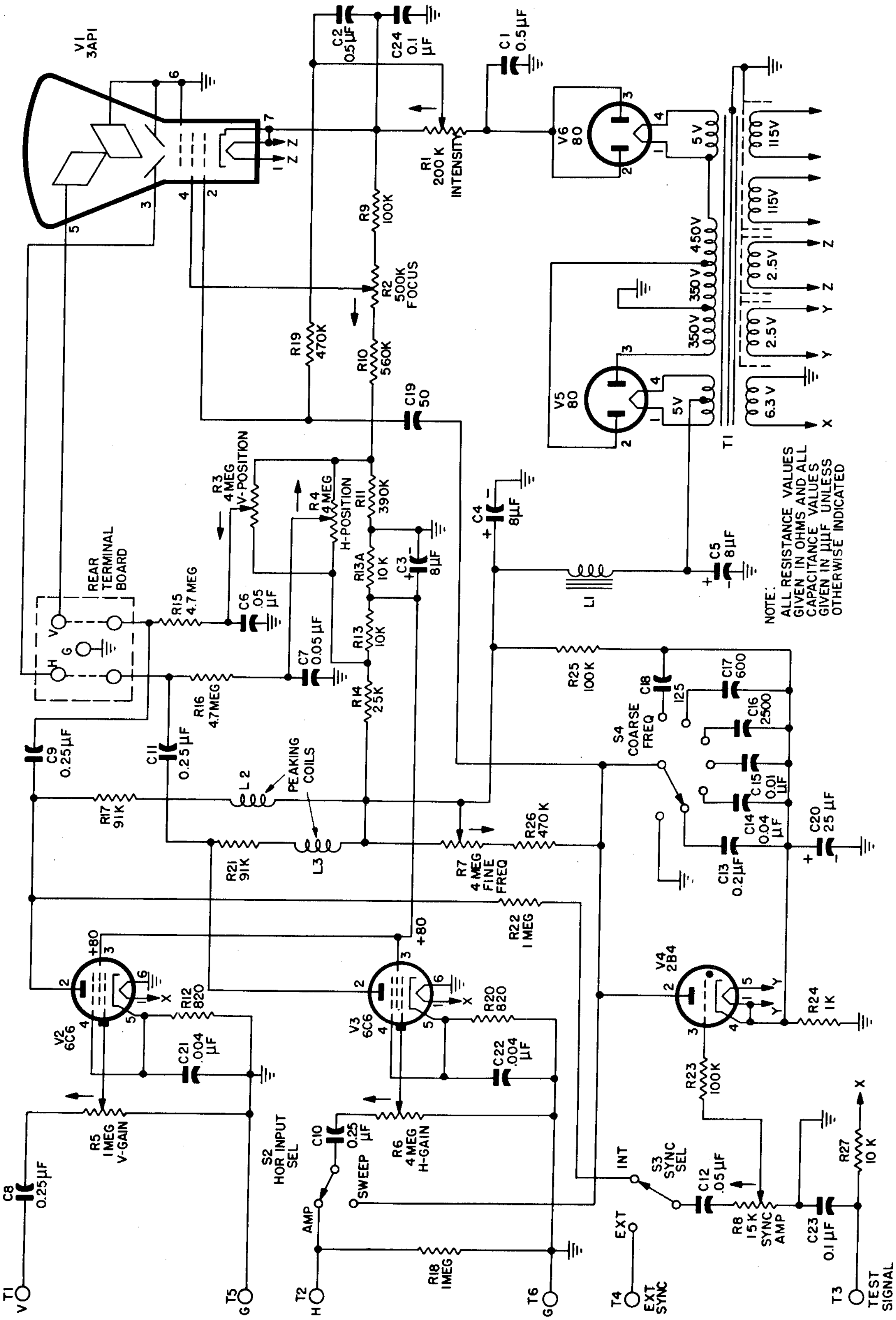


Figure 2-50. Over-all Schematic Diagram of a Basic Oscilloscope

quantity for each multiplier setting, and is marked beside the corresponding switch position. A probe containing an L-pad extends the voltage range to 450 volts, at the expense of a 10-to-1 reduction in sensitivity. Use of an external voltage divider will further extend the voltage range.

(*b*) MARKER GENERATOR AND ASSOCIATED CIRCUITS.—The marker generator (refer to block diagram, figure 2-49) consists essentially of an oscillator, the tuned circuit of which is normally damped heavily by the conductance of a control (or clamping) tube. This tube is cut off by a pulse, which is supplied by the enabling pulse generator thus initiating the timing marker oscillations in synchronism with each sweep. The marker generator includes amplifying and pulse-shaping circuits and a rotary ganged switch which is used to change the circuit constants that determine the marker-pulse intervals, and also to shut off the marker generator. These sharp negative pulses are applied to the cathode of the cathode-ray tube. Each pulse makes the cathode more negative with respect to the control grid, and therefore intensifies the electron beam; hence, a series of bright timing dots is produced on the screen as the beam sweeps across. Since the marker generator is controlled by the enabling pulse, the first of each series of markers nearly coincides with the start of the sweep.

Synchronizing pulses, which are obtained either internally (from vertical amplifier or trigger generator) or externally, enter the sweep channel by means of a sync selector switch and then pass through an amplifier to the enabling-pulse generator. This generator supplies square waves to energize the sweep and marker generators, and also supplies positive pulses to unblank the electron beam, which up to this time has been blanked by the negative voltage on the cathode-ray-tube control grid. The enabling pulse passes to the sweep generator, where the basic voltage waveform (sawtooth) that sweeps the electron beam horizontally across the screen originates. The stability control is a screwdriver adjustment used to control the oscillating point of the enabling-pulse generator.

The trigger-pulse generator consists of a rate-governing continuous oscillator, an amplifier, and a pulse-generating circuit similar to a blocking oscillator but operating only (one cycle at a time) under control of the rate-governing oscillator. When desired, this trigger generator supplies positive 25-volt four-microsecond pulses for triggering external circuits at the rate of 300, 800, or 2000 times per second. Simultaneously, through an internal connection, the trigger generator also provides similar pulses of lower amplitude for synchronizing the sweep circuit of the oscilloscope.

(6) OPERATING CONTROLS AND TERMINALS.—Table 2-5 gives the names and functions of the operating controls and terminals of a basic oscilloscope.

TABLE 2-5. OPERATING CONTROLS AND TERMINALS OF A BASIC OSCILLOSCOPE

NAME OF CONTROL	REFERENCE SYMBOL	FUNCTION
VERTICAL POSITION	R3	Changes the d-c potential of the vertical-deflection plate, and thus controls the vertical position of the trace.
HORIZONTAL POSITION	R4	Changes the d-c potential of the horizontal-deflection plate, and thus controls the horizontal position of the trace.
INTENSITY	R1	Changes the voltage of the grid of the cathode-ray tube, and thus controls the intensity of the trace.
FOCUS	R2	Changes the voltage of the focusing electrode of the cathode-ray tube, and thus adjusts the focal point of the beam.
VERTICAL GAIN	R5	Changes the voltage of the input signal applied to the grid of the vertical amplifier, thus controlling the amplitude of the vertical signal.
HORIZONTAL GAIN	R6	Changes the voltage of the input signal applied to the grid of the horizontal amplifier, thus controlling the amplitude of the horizontal signal. (Input signal is produced by the time-base generator or by an external signal source.)
COARSE FREQUENCY	S4	Selects the various sweep capacitors. This switch provides a rough adjustment of the sawtooth oscillator frequency.
FINE FREQUENCY	R7	Provides a fine adjustment of the sweep frequency by controlling the rate at which the selected sweep capacitor is charged.
SYNC. AMP.	R8	Varies the amplitude of the synchronizing voltage applied to the time-base generator, thus enabling the operator to "lock-in" the signal being viewed.
SYNC. SELECTOR	S3	Provides a means for the operator to select a synchronizing signal from either an internal or an external source.
VERTICAL INPUT	T1	Provides a terminal for the connection of an external signal source to the vertical amplifier.

TABLE 2-5—Continued

NAME OF CONTROL	REFERENCE SYMBOL	FUNCTION
HORIZONTAL INPUT	T2	Provides a terminal for the connection of an external signal source to the horizontal amplifier.
TEST SIGNAL	T3	Provides a terminal for a 60-cycle output voltage of approximately 6 volts a-c rms.
EXT. SYNC.	T4	Provides a terminal for connecting the external synchronizing-signal source.
GROUND	T5 T6	These binding posts are used to ground the chassis of the oscilloscope to the ground of any input signal source.
HORIZONTAL INPUT SELECTOR	S2	Allows either an external signal or the internally generated sawtooth sweep signal to be applied to the horizontal-amplifier grid.

(7) OPERATING PRECAUTIONS. — Personnel who use or maintain oscilloscopes are advised to observe closely the following precautions:

(*a*) Do not operate an oscilloscope with the case removed. High voltage which could cause fatal shock is exposed.

(*b*) Magnets or any device in which a magnetic field is present should not be placed on or near an oscilloscope. A magnetic field causes erratic deflection of the electron beam, resulting in pattern distortion and erroneous indication.

(*c*) Do not permit a bright spot to remain stationary on the fluorescent screen, because the energy of the electron beam concentrated in a small area will burn the screen.

(*d*) Voltages exceeding the manufacturer's specifications should not be applied to the input terminals of the oscilloscope. These values are the normal ratings of the input capacitors to the horizontal and vertical amplifiers of the basic oscilloscope. The exact input values for the test equipment being used should be determined from the instructions supplied with the equipment.

b. LISSAJOUS FIGURES. — In addition to having an operational knowledge of the oscilloscope controls, the technician needs to understand how the voltages on the vertical- and horizontal-deflection plates combine to form a resultant pattern on the oscilloscope screen. In paragraph 2-8.*a.*(1)(*b*)*1.* it was shown that, when two d-c potentials are applied simultaneously to the horizontal- and vertical-deflection plates, the position of the spot at any instant is due to the resultant electrostatic force of the two voltages acting at that instant. In figure 2-51, a sawtooth wave is applied to the horizontal-deflection plates of an oscilloscope, and a sine wave is applied to the vertical-deflection plates. As the sawtooth waveform increases in amplitude, it causes the electron beam to travel across the screen at a linear rate. Simultaneous with its horizontal motion, the electron beam is deflected vertically in accordance with the variations in amplitude of the sine wave. Therefore, a true reproduction of the sine-wave voltage with respect to time (or of any other alternating voltage applied to the vertical-deflection plates) appears on the cathode-ray-tube screen. This statement can be verified by making a point-to-point plot of the waveforms, two points of which are shown in figure 2-51. It is also possible to use a sine-wave voltage as the input to the horizontal-deflection plates. When two sine-wave

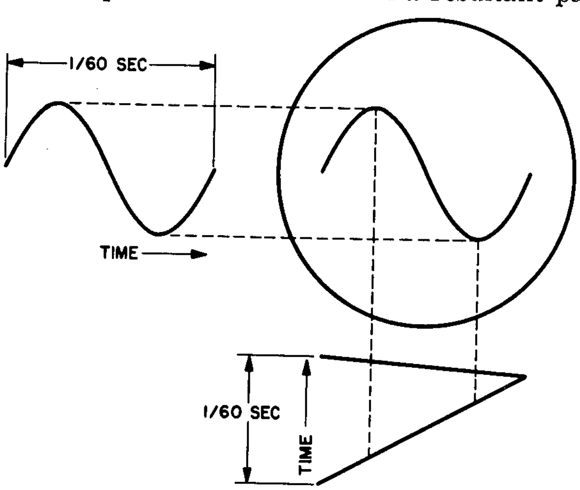


Figure 2-51. ***Pattern Formed As a Result of Using Linear Time Base***

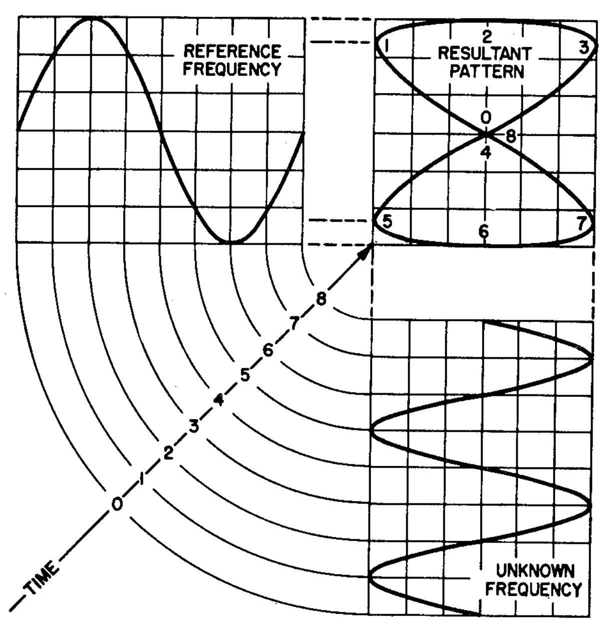


Figure 2-52. ***Formation of a Lissajous Figure Illustrating 2:1 Frequency Ratio***

voltages are fed to the deflection system of a cathode-ray tube, the resultant pattern is known as a Lissajous figure. Lissajous figures are used in frequency and phase measurements.

(1) FREQUENCY MEASUREMENT. — Figure 2-52 shows the formation of a Lissajous figure using two sine waves of different frequencies (2:1 ratio). The appearance of the resultant Lissajous pattern may be determined by joining intersections of projections from like-numbered points of the waveforms. The ratio of the two frequencies can be determined by counting the number of loops along the top (or bottom) edge of the pattern and the number of loops along the right (or left) edge and substituting the results in the following formula.

$$\frac{\text{Frequency on horizontal axis}}{\text{Frequency on vertical axis}} = \frac{\text{Number of loops counted on right edge}}{\text{Number of loops counted on top edge}}$$

Figure 2-53 shows four Lissajous patterns for ratios commonly encountered in frequency measurements. The accuracy of frequencies measured by this method is limited by the accuracy of the reference frequency, and by the care used in counting the loops. Lissajous patterns constantly change form because of slight variations, in phase and frequency, between the reference signal and the signal under test. This constantly changing pattern increases the difficulty encountered in counting the loops. Patterndrift and the consequent difficulty in counting the loops limit this type of frequency measurement to a practical ratio of 10:1. However, if extreme care is used in counting and if the gain of the oscilloscope is increased, it is possible to count as many as 30 loops.

(2) PHASE MEASUREMENT.—Lissajous figures can also be used to measure the phase relationship existing between two voltages of the same frequency. The patterns involved appear as ellipses with different degrees of eccentricity. The pattern is formed, as shown in figure 2-54, when two sine waves of the same frequency are applied to the vertical and horizontal input terminals of the oscilloscope. Point-to-point plotting of like-numbered projections, as was previously done for frequency measurement, will verify the formation of the resultant pattern. It can readily be seen that if two sine waves of unequal amplitude were used, the resultant pattern would always be elliptical in form and could not be intelligently used. In actual phase measurement unequal amplitudes at the input are compensated for by adjusting the vertical and horizontal gain controls of the oscilloscope. If one of the applied frequencies is constantly changing phase with respect to the other, the resultant ellipse constantly changes form, and the plane of the ellipse appears to rotate around either of two imaginary diagonal axes. As the phase difference increases from zero to 90 degrees, the plane of the ellipse appears to rotate around one of the imaginary diagonals, and as the phase difference increases from 90 degrees to 180 degrees the plane of the ellipse rotates around the opposite diagonal axis. See figure 2-55. At the zero- and 180-degree points of phase difference, the resultant patterns appear as diagonal lines, and at the 90-degree point the pattern is a circle.

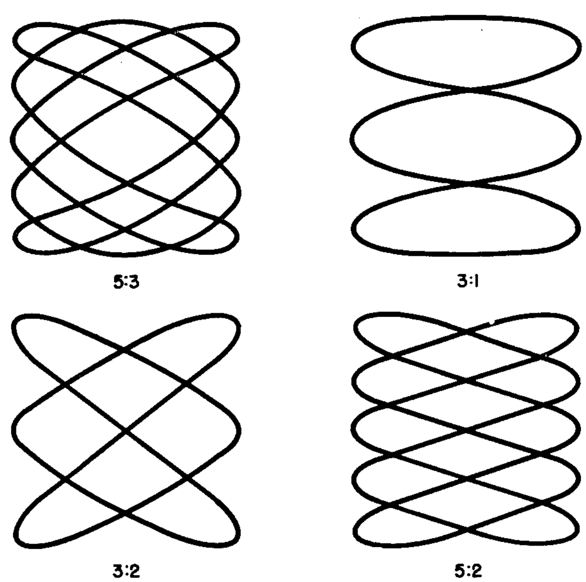


Figure 2-53. Lissajous Figures, Showing Some Common Frequency Ratios

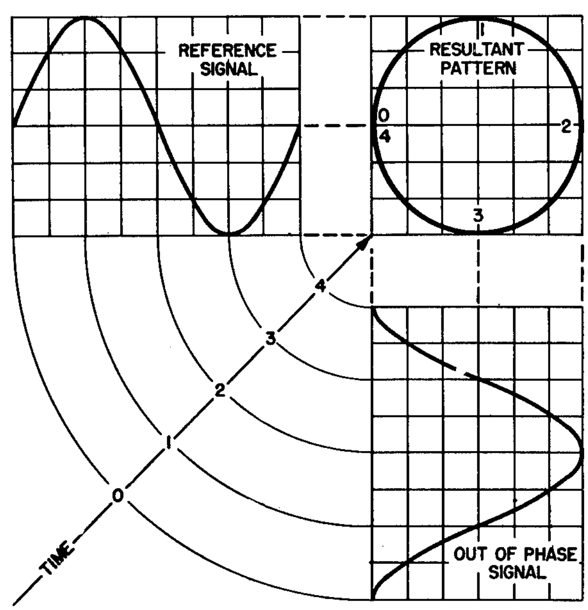


Figure 2-54. Formation of a Lissajous Figure, Illustrating 90 Degrees Phase Difference

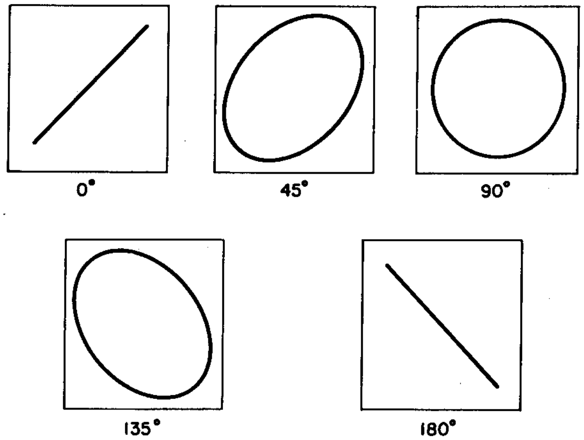


Figure 2-55. Lissajous Figure, Showing 0 to 180 Degrees Phase Difference

(a) DETERMINATION OF PHASE ANGLE.—In order to measure the angle of phase displacement, it is necessary to use an oscilloscope with a cross-section screen to provide a graph of the X- and Y-axis ordinates. The vertical and horizontal gain controls of the oscilloscope are set to zero position, and the spot is centered at the intersection of the X and Y axes. After the test signals are applied to the vertical and horizontal inputs of the oscilloscope, the gain controls of each amplifier are adjusted to provide a trace that extends equally, by an arbitrary number of divisions, in both the X and Y directions. Count the number of divisions along the Y axis to the point at which the ellipse intersects that axis. This number is known as the Y-axis intercept. Count the number of divisions along the Y axis to the point on that axis which indicates the maximum amplitude of the ellipse. This number is known as the Y-axis maximum. The angle of phase difference (Θ) is found by substituting these values in, and solving, the following equation:

$$\text{Sine } \Theta = \frac{\text{Y-axis intercept}}{\text{Y-axis maximum}}$$

c. INTERPRETATION OF OSCILLOSCOPE PATTERNS. — One of the most important steps in waveform analysis — the one which usually proves the most difficult for personnel inexperienced with oscilloscope work — is the proper interpretation of the patterns viewed on the oscilloscope screen. It should be borne in mind that the unknown signal is always plotted as a function of a signal whose characteristics are known. If the characteristics of the signal on one axis are not known, then it will be almost impossible to identify or interpret the signal under investigation on the other axis. For this reason, it is generally common practice to use on the horizontal axis a sawtooth (or sinusoidal) waveform of a known frequency which is synchronized with the fundamental or some integral submultiple of the frequency under test. Since the sawtooth waveform gives horizontal deflection which is linearly proportional to time, it provides a plot of the wave shape of the unknown signal versus time. Whether the observed pattern is a true reproduction of the signal under test is largely determined by the limitations of the particular oscilloscope available for use. The basic oscilloscope is limited by the following circuit characteristics, which are inherent in the design of the test equipment frequency response and sensitivity of both the vertical and horizontal amplifiers, namely, phase distortion, input impedance, and the maximum permissible input signal. The degree that these circuit characteristics influence the reproduction of waveforms is determined for the most part by design considerations involving compromises between production costs and over-all test equipment utility. The effect of these circuit characteristics on waveforms will be discussed in the paragraphs to follow, so that the technician can recognize waveform distortion caused by these characteristics and be better prepared to interpret the observations.

(1) WAVEFORM DISTORTION.—For purposes of discussion, waveforms can be considered, as simple (consisting of a fundamental sine wave) or complex (having harmonic content, such as a sawtooth or square wave). When both simple and complex waveforms pass through an amplifying circuit having a definite frequency response, their output waveforms are affected (distorted) in a different manner. The sine wave can suffer only a loss of amplitude, whereas, the complex waveform, because of its harmonic content, can be distorted in both amplitude and wave shape. Therefore, when viewing waveforms having harmonic content, the technician must consider the frequency response of the amplifiers in the oscilloscope being used. The horizontal amplifier is used to amplify a sawtooth waveform, the frequency of which varies broadly. Because of the harmonic content of this waveform, it is possible that a non-linear (distorted) sweep may develop at the horizontal output, becoming more pronounced as the frequency increases. For this reason, signals under observation should be viewed on the fundamental and on several integral submultiples of the sweep voltage. The resultant single, double, triple, etc., presentations should be compared with each other, and the pattern which provides the best linearity should be used.

The frequency response of the vertical and horizontal amplifiers of the basic oscilloscope shown in figure 2-50 extends from about 5 cps to 100 kc. Since this frequency response has proved inadequate for many test applications, an oscilloscope having a frequency response extending

from 5 cps to 2 mc is now considered as a general-purpose oscilloscope. For true reproduction and proper evaluation of complex waveforms, a synchroscope having special circuits for pulse analysis (figure 2-49) is used. This type of oscilloscope has a very broad frequency response, extending from about 3 cps to 11 mc.

When a complex waveform is passed through an R-C network (usually coupling), some of the harmonic components may develop a time lead with respect to the other components. This change in the waveform is known as phase distortion, and is most pronounced at either end of the amplifier response curve. If the R-C coupling network contains a variable resistor (gain control), the degree of phase distortion of a particular frequency varies, depending upon the setting of the control. At the lower frequencies the resistance of the potentiometer is the determining factor; at the higher frequencies the inherent distributed capacitance of the rotor affects the phase relationship of the harmonic components. Insofar as the oscilloscope is concerned, only complex waveforms are affected by phase distortion. While it is true that a simple (fundamental) waveform may develop a time lead or lag the resultant wave shape is unaltered.

Stray pickup may be another cause of waveform distortion. To avoid such pickup, make the leads from the circuit under test as short as possible. In some cases the pickup may be so disturbing that it is almost impossible to use an oscilloscope. A few things can be done to reduce the effect of stray fields on the oscilloscope: First, the cathode-ray tube itself must be very carefully shielded. In most cases, this shielding is provided by the aquadag coating within the tube and, also, by a metallic shield surrounding the outside of the tube. Second, the common side of the oscilloscope circuit should be connected to a ground point in the circuit under test and also to a good external ground connection, to eliminate most of the stray voltages that are picked up by the leads. Third, a low-capacitance coaxial cable may be used to reduce still further the effect of stray fields.

(2) PROCEDURE FOR WAVEFORM OBSERVATIONS.—Use of the oscilloscope to observe waveshapes when tracing signals is especially indispensable when circuits contain more than one type of signal. This is true when observing composite signals which contain synchronizing pulses and video information on the same transmitted carrier. At different horizontal sweep frequencies the oscilloscope will allow the various composite signals to be displayed. A technician should be familiar enough with the equipment under test to know approximately what type of waveshape to expect, its approximate frequency, and at what point in the circuit. The following procedure should be followed for viewing waveshapes.

(*a*) Connect the vertical-input terminal to the point under test, and connect the ground terminal to the ground return of the circuit under test. To avoid distortion, make sure that a good ground connection is made to the equipment under test and to the oscilloscope.

(*b*) To observe one complete cycle of the desired waveshape, set the oscilloscope sweep to the same frequency as the signal to be observed. To observe two complete cycles, set the oscilloscope sweep to one-half the frequency of the waveshape under observation. Using the coarse and the fine frequency controls and the sync amplitude control, adjust until the observed waveshape is at a standstill. To avoid unnecessary waveshape distortion, use only the necessary amount of sync amplitude for stopping the waveshape motion.

(*c*) To observe a waveshape of an unknown frequency, follow steps (*a*) and (*b*), with the exception that the coarse and fine frequency controls must be adjusted until a position is found where the waveshape is at a standstill. The approximate frequency of the observed signal may be read from the coarse and fine frequency dials. If the signal to be examined is of a radio frequency, a detector probe must be used in conjunction with the oscilloscope.

2-9. MODULATION MEASUREMENT.

Modulation is a process that permits the transmission of intelligence on an r-f carrier, and is accomplished by varying one or more characteristics of the carrier in accordance with the intelligence to be transmitted. The characteristics which can be varied are amplitude, frequency, and phase. The type of modulation is designated by the particular characteristic selected to be varied.

a. TYPES OF MODULATION.—The original, and still the most commonly used, type of modulation in the field of electronics is amplitude modulation. This type of modulation has one major disadvantage—its susceptibility to noise. To overcome, in most cases, this disadvantage, another type of modulation known as frequency modulation is used. Similar to frequency modulation, but infrequently used, is phase modulation. The principal difference between the latter two types of modulation lies in the device which produces the modulation. A circuit which is able to demodulate a frequency-modulated wave can also be used without any change to demodulate a phase-modulated wave.

(1) AMPLITUDE MODULATION.—Amplitude modulation is defined as the process of

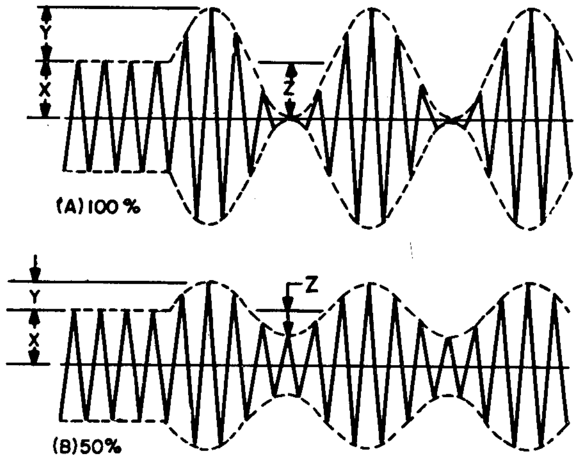


Figure 2-56. Amplitude-Modulated Waves, Showing Percentages of Modulation

changing the amplitude of an r-f carrier wave in accordance with the intelligence to be transmitted. The r-f carrier portion of an amplitude-modulated wave is of fixed frequency and constant amplitude. An audio modulating frequency is superimposed on the carrier in a manner that causes the amplitude of the carrier signal to vary in the same manner as the superimposed sine wave shown in figure 2-56 causes its carrier to vary, leaving the carrier frequency unchanged.

An amplitude-modulated wave is composed of a number of frequencies: the radio frequency of the carrier wave, the modulating audio frequency (or frequencies), and the sum and difference frequencies resulting from the heterodyning of these two frequencies. The sum and difference frequencies are known as sideband frequencies and carry the intelligence in the amplitude-modulated wave. When an r-f carrier is modulated by many audio frequencies, such as occur in speech or music, the side frequencies constitute a band of frequencies above and below the carrier frequency. The width of this band is determined by the highest modulating frequency.

(*a*) MODULATION PERCENTAGE. — The degree of modulation of an amplitude-modulated wave is expressed as a percentage of the amplitude deviation from the unmodulated value. A carrier wave is 100-percent modulated when the total amplitude variation from crest to trough is equal to twice the unmodulated amplitude. This is shown in figure 2-56, part (A). Part (B) of the same figure illustrates a carrier with 50 percent modulation. The percentage modulation of any AM carrier can be found by dividing either Y or Z by X and multiplying the result by 100. If the modulating signal is not symmetrical, the larger of the two (Y or Z) should be used.

(*b*). POWER IN MODULATED WAVE. —In order to attain 100 percent modulation of an r-f carrier with a sine-wave audio frequency, a modulating power equal to one-half of the r-f carrier power is required. Under this condition, the average power of the modulated carrier is equal to 1.5 times the average unmodulated carrier power. The added power is divided equally between the upper and lower sidebands. During the peaks of 100 percent modulation, the amplitude of the carrier is doubled, and the instantaneous peak power is equal to four times the instantaneous unmodulated peak power.

When voice modulation is used, only the highest-amplitude peaks can be permitted to modulate the carrier 100 percent. Since many a-f speech components do not modulate the carrier 100 percent, the average power required for voice modulation is less than that required for modulation with a sine wave. It has been determined that voice peaks usually modulate a carrier 100 percent when the average carrier output power is increased 25 percent over its normal value.

(2) FREQUENCY AND PHASE MODULATION.—In frequency modulation the carrier amplitude remains constant and the output frequency of the transmitter is made to vary about the carrier (or mean) frequency at a rate corresponding to the audio frequencies of the speech currents. The extent to which the frequency changes in one direction from the unmodulated, or carrier, frequency is called the frequency deviation. It corresponds to the change of carrier amplitude in the amplitude-modulated wave, as may be seen by comparison of part (A) with part (B) of figure 2-57. Deviation is usually expressed in kilocycles, and is equal to the difference between the carrier frequency and either the highest or lowest frequency reached by the carrier in its excursions with modulation. There is no modulation percentage in the usual sense. With suitable circuit design the deviation may be made as large as desired without encountering any effect equiv-

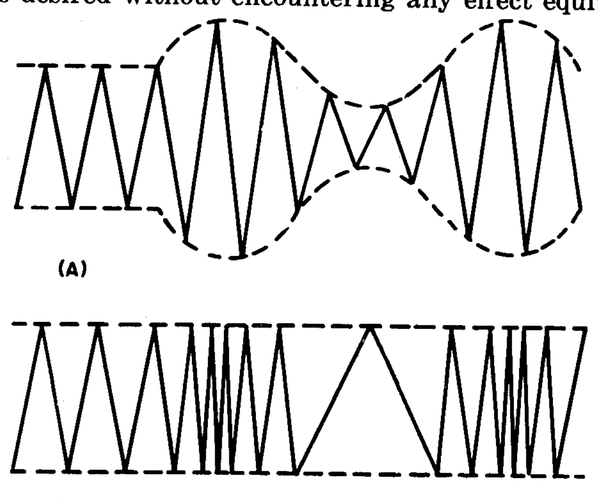


Figure 2-57. Comparison of Amplitude-Modulated Wave (A) and Frequency-Modulated Wave (B)

alent to overmodulation in the amplitude system. However, the maximum permissible deviation is determined by the width of the band assigned for station operation. In FM broadcasting, the band is limited to 75 kc either side of the carrier center frequency. In amplitude modulation, 100 percent modulation occurs when the amplitude of the carrier varies from zero to twice its unmodulated value. In frequency modulation, the equivalent of 100 percent modulation occurs when the frequency deviation is made equal to the predetermined maximum.

(*a*) MODULATION INDEX.—The ratio of the maximum frequency deviation to the audio frequency of the modulation is called the modulation index, or deviation ratio. Unless otherwise specified, it is taken as the ratio of the maximum frequency deviation to the highest audio frequency to be transmitted. This ratio is generally given as a whole number. For example, if a station is permitted a deviation of 75 kc and the highest audio frequency to be transmitted is 15 kc, the modulation index is 5.

(*b*) PHASE MODULATION.—In phase modulation, the instantaneous phase relationship between the modulated and the unmodulated carrier is varied in accordance with the intelligence to be transmitted. During a change in phase, the instantaneous frequency of the modulated carrier also changes; that is, during phase modulation both the instantaneous phase angle and the instantaneous frequency of the r-f carrier are varied. From figure 2-57, part (B), it can be seen that each cycle of the FM wave is not sinusoidal. The same waveshape can be produced by changing the phase of the sine wave from point to point over one cycle. Conversely, a change of phase in this manner corresponds to a change in frequency, so that a phase-modulated wave is similar to a frequency-modulated wave. Identical receivers may be used to receive PM and FM transmissions. Since phase variations are essentially equivalent to frequency variations, phase modulators are used to develop frequency modulation. Although essentially the end result is the same, phase modulation has the advantage that the carrier frequency can be stabilized (e.g., with a crystal oscillator) and the modulated carrier produced by phase variations, whereas in frequency modulation the r-f carrier must be permitted to change frequency with modulation.

b. AMPLITUDE-MODULATION-PERCENTAGE MEASUREMENT.—The two methods that are commonly used to measure the modulation percentage of an AM carrier are discussed below. The first method, which is based on the fact that the antenna current increases with the degree of modulation, is a fast means of determining the approximate modulation percentage. The second method, which uses an oscilloscope, is a fairly accurate method in common use.

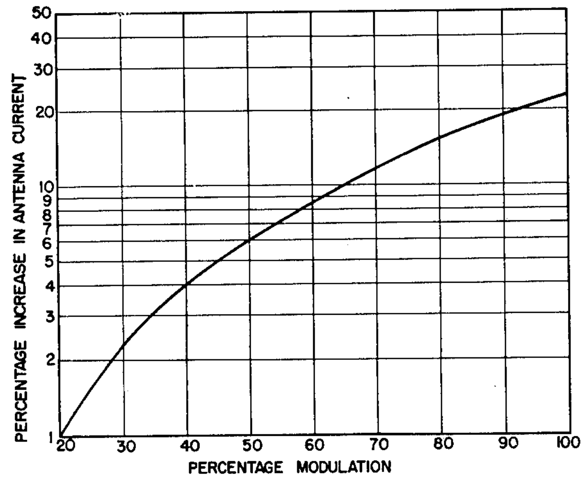


Figure 2-58. Antenna-Current Increase with Amplitude Modulation

(1) ANTENNA CURRENT METHOD.—It was shown in paragraph 2-9.*a.*(1)(*b*) that the power delivered to the antenna increases with modulation, the added energy existing in the sidebands of the carrier. This increase of power output is indicated by an increase of antenna current. Hence, the increase of antenna current can be taken as a measure of the degree of modulation, which can be expressed as a percentage, as shown in figure 2-58. The graph for this figure was developed from the relationship existing between the carrier power and the increased power resulting from the added modulation power. Since current is proportional to the square root of power, it is possible to calculate the modulation percentage using the following formula.

$$\text{Modulation percentage} = \sqrt{\frac{2(I_m^2 - I_c^2)}{I_c^2}} \times 100$$

where I_m equals the value of antenna current after modulation, and I_c equals the value of antenna current before modulation.

(2) OSCILLOSCOPE METHOD.—The cathode-ray oscilloscope is widely used as an amplitude-modulation monitor and measuring instrument. Since it is capable of presenting visual indications of the modulated output of AM transmitters, the oscilloscope is a fairly reliable instrument for detecting overmodulation and determining the percentage of modulation. Three types of modulation patterns are provided by the oscilloscope depending upon the hook-up used. When coupled to the tank circuit as shown in figure 2-59, the oscilloscope displays a pattern which has the actual shape of the modulation envelope, because the oscilloscope linear time base (sawtooth wave) is used to sweep the horizontal

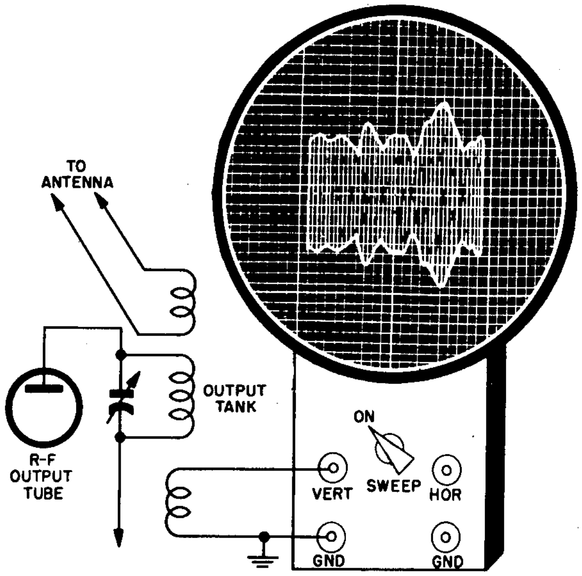


Figure 2-59. Method Used to Monitor Amplitude-Modulated Carrier

axis. Since the wave-envelope pattern varies continuously with modulation, it is difficult to obtain an accurate modulation percentage measurement using this presentation; however, this type of presentation is readily adaptable for use in monitoring modulated outputs, and provides a means of quickly detecting overmodulation.

When the oscilloscope is connected as shown in figure 2-60, the waveform presentation shows the modulated carrier amplitude plotted as a function of the modulating voltage—rather than a function of time, as used in figure 2-59. The pattern resulting from the use of the modulating voltage as a sweep is known as a trapezoidal pattern. This type of pattern is used to determine the modulation percentage as follows: With the oscilloscope connected as shown in figure 2-60 and with the modulator not operating, a single vertical trace which represents the carrier voltage appears on the oscilloscope screen. The vertical trace is centered horizontally, and then its height is set to an arbitrary number of divisions by means of the vertical gain control. When the modulator is put into operation, the pattern assumes its trapezoidal characteristics, similar to the pattern shown in figure 2-60. At this time the oscilloscope horizontal gain control is adjusted to provide a usable pattern within the limits of the screen. By counting the number of divisions that the modulating voltage causes the carrier amplitude to increase or decrease (indicated by H_1 and H_2, respectively, in figure 2-60) from its former level

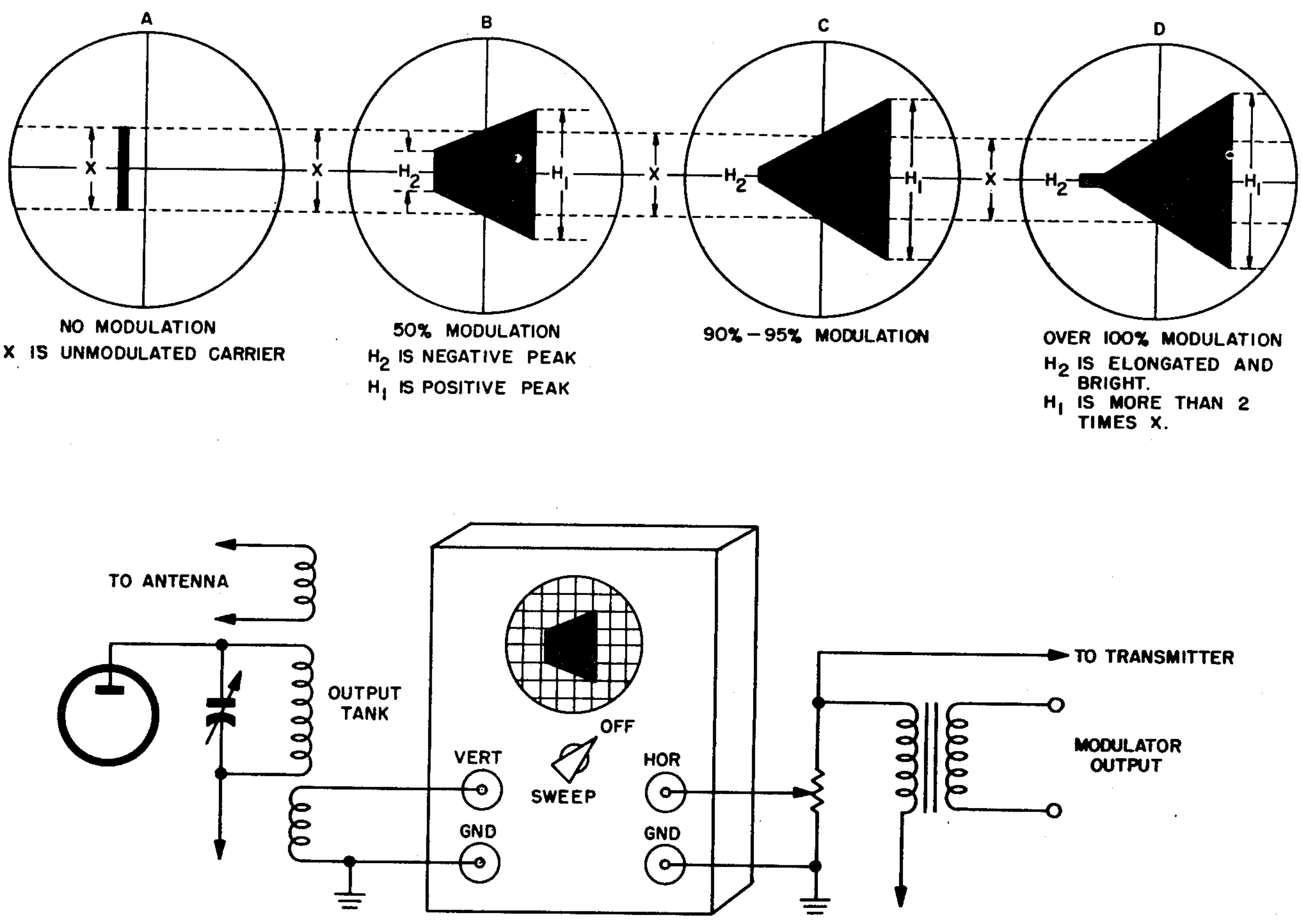


Figure 2-60. Method Used to Measure Amplitude Modulation Percentage

(X) and substituting that value in the formula given below, the technician can easily calculate the modulation percentage.

$$\text{Modulation percentage} = \frac{H_1 - H_2}{H_1 + H_2} \times 100$$

The longer side of the trapezoidal pattern represents modulation peaks, or crests; the shorter side indicates modulation troughs, or low points. At 100 percent modulation, the wedge-shaped pattern assumes a point on the shorter side; modulation over 100 percent causes this point to extend and form a horizontal line or tail. Because the trapezoidal type of pattern retains its triangular characteristics with varying degrees of modulation, it provides a more easily discernible indication of overmodulation, and also lends itself more readily to measurement of modulation percentage. To obtain correct results, care should be taken to avoid stray r-f pick-up which may distort the scope presentation.

Another method of measuring percentage of modulation of an AM signal is shown in figure 2-61. This method is not generally used because it requires the use of a receiver tuned to the transmitter frequency. After oscilloscope connections are made as shown in figure 2-61, it may be necessary to retune the i-f stage to compensate for the additional loading effect. The oscilloscope pattern is an ellipse having a single sharp line, and is the result of a phase difference between the vertical and horizontal deflection voltages fed to the oscilloscope. This phase difference is produced by the horizontal amplifier input capacitance and the 50,000-ohm resistor.

As shown in figure 2-62, the unmodulated pattern is an ellipse having a single, sharp line. This line broadens to a ribbon with modulation. For 100 percent, the dark area in the center of the pattern decreases to zero. This point may be de-

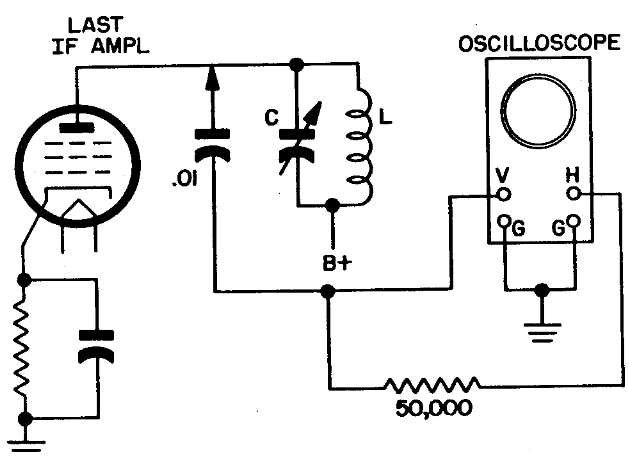


Figure 2-61. ***Percent Modulation Measurement Using Oscilloscope***

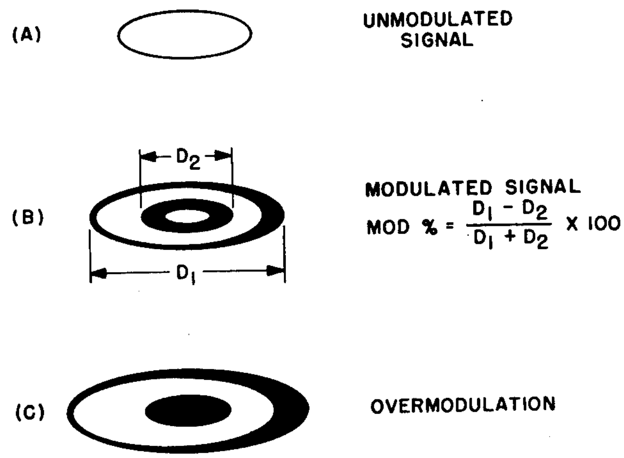


Figure 2-62. ***Modulation Measurement Waveforms***

termined with accuracy. Overmodulation goes beyond this point and a bright spot appears in the center of the pattern. The modulation percentage may be calculated by the formula given in figure 2-62.

(3) MODULATION METERS. — Various types of peak voltmeters have been designed to determine accurately the percentage of modulation. These meters are capable of constantly checking on the modulation frequency even during the complex modulation of voice transmission. This is accomplished by a time-lag circuit of resistance and capacitance in conjunction with the indicating meter. The needle of the indicating meter follows peaks of modulation, and will momentarily stay at this deflected position, thereby permitting a good check on the modulation percentage, even during peaks.

The transmitter carrier is magnetically coupled to the input of the modulation meter. The input of the modulation meter must be tuned to the transmitter carrier frequency to develop sufficient potential for operation of the modulation meter.

c. FREQUENCY DEVIATION MEASUREMENT.—Since frequency and phase types of modulation always take place at a low level in the transmitter system, modulation can be checked and measured when r-f sections of these transmitters are not in operation. Since zero frequency is equivalent to dc, it is possible to apply a variable d-c voltage to the modulator grid and produce proportional changes in the oscillator frequency. A suitable frequency-measuring instrument is set to the maximum or minimum allowable oscillator excursion, and the d-c voltage is adjusted to change the oscillator frequency to the point at which a zero-beat note is obtained. The value of the d-c voltage at this point is equal to the peak a-c modulating voltage which would satisfy the maximum allowable condition, and is the equivalent of 100 percent modulation. The

final carrier frequency, of course, is the oscillator frequency times the multiplication factor of multiplying stages. Hence, the final carrier deviation is the oscillator deviation times the same multiplication factor. In some FM transmitters use is made of an electron-ray tube (6E5 or equivalent) as a modulation monitor.

2-10. STANDING-WAVE MEASUREMENT.

In the following paragraphs the fundamentals of standing waves will be discussed before discussing standing-wave measurements. Since the presence of standing waves on an r-f transmission line represents a loss of power, the reason they exist and how to measure them are of great importance.

a. FUNDAMENTALS OF STANDING WAVES.—For discussion purposes the infinite line will be discussed first, after which the finite line and standing-wave ratios will be considered.

(1) THE R-F TRANSMISSION LINE.—If an impedance is connected across the output terminals of an r-f generator, a definite current flows through it. The amplitude of this current depends upon the value of the impedance and the voltage of the generator. However, if an r-f transmission line of random length is connected to the same r-f generator and is terminated in an impedance, other than the characteristic impedance of the line, the value of current does not equal the expected value. This indicates that there are other factors besides the series impedance of the line and load, and that these factors have an effect on the impedance of the line. These factors, which include series resistance, series inductance, shunt capacitance, and shunt resistance, are present to some degree in every transmission line, and they make up what is known as the characteristic impedance of the line.

(*a*) LINE OPEN-CIRCUITED AT LOAD END.—An r-f transmission line open-circuited at its load end has infinite impedance at that point. When a generator is connected to such a line, current and voltage waves travel along the line toward the load end. When they reach the load end, they encounter an infinite impedance, which prevents the flow of current; therefore, the load is unable to absorb the energy represented by the current and voltage, as may be shown by a simple calculation of the power absorption: $P = I^2R = 0 \times R = 0$. This energy can neither continue on, nor remain there, nor disappear, nor be absorbed by the infinite impedance. Therefore, it must reverse its direction and return over the line to the generator. Since the reversal of direction of the energy travel is somewhat similar to the reflection of light waves from the surface of a mirror, the term "reflection" is used to describe the effect that takes place at the open-circuited end of the transmission line.

(*b*) LINE SHORT-CIRCUITED AT LOAD END.—A length of r-f transmission line that is short-circuited at its load end has zero impedance at that point. When a generator is connected to such a line, current and voltage waves travel along the line toward the load end, as they did in the case of the line with the open-circuited end. When the waves reach the load end of the line, they encounter zero impedance, which is unable to absorb the energy represented by the current and voltage, as again may be shown by a simple calculation: $P = I^2R = I^2 \times 0 = 0$. Therefore, for this condition the energy must also reverse its direction and return over the line to the generator. Thus, energy is reflected from a short-circuited end of a transmission line, as well as from an open-circuited end.

(*c*) THE INFINITE LINE.—The infinite line is an imaginary transmission line of infinite length, which, while impossible to construct, is an important subject to study because the behavior of any actual line can be understood from that of the infinite line. If an r-f generator were connected to an infinite line it would "see" (that is, deliver energy into) a definite impedance. In the case of an infinite line, both the input and output impedances would be equal, and each would have the same value as the characteristic impedance of the line. With the r-f generator connected to the infinite line, current and voltage waves would travel along the line toward the far end, which, of course, they would never reach. These current and voltage waves would always be in phase. An r-f transmission line of finite length terminated in an impedance equal to its characteristic impedance and connected to a generator, presents to a generator the same impedance as that of an infinite line.

(2) ANALYSIS OF STANDING WAVES.—The manner in which standing waves are produced on a transmission line can be more easily understood if a mental image is formed of an alternating current traveling through a wire of infinite length. At any point along the conductor the current is continually changing from zero to a maximum in one direction, back to zero, to a maximum in the other direction, and to zero again. The number of complete cycles that occur per second is expressed as the frequency. Disregarding line attenuation the conduction process may be presented pictorially as a sine wave of current moving along an infinite line or conductor at a definite velocity, v, as shown in part (A) of figure 2-63. As the sine wave travels past a particular point, represented by the line XY, the

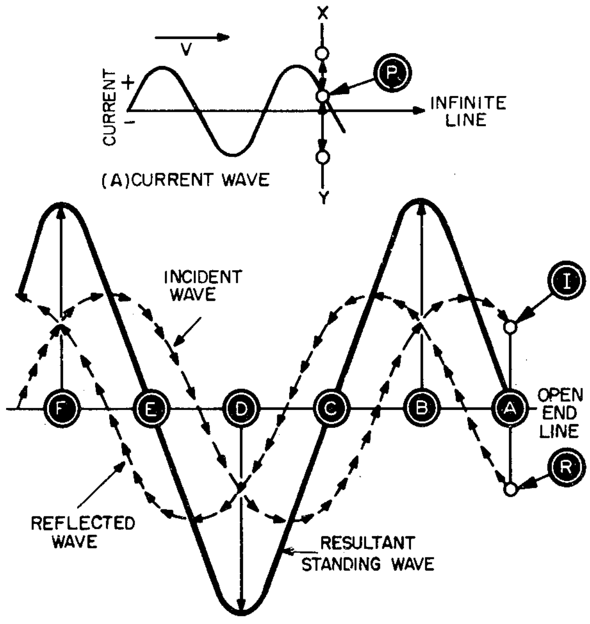


Figure 2-63. Development of Standing Waves

value of current at any instant is represented by the instantaneous vertical position of point P referenced to the horizontal axis. Since the frequency determines the number of cycles that pass a specific point per second, the relationship between wavelength (λ), velocity (v), and frequency (f) can be expressed by the formula:

$$\lambda = \frac{v}{f}$$

In the representation of the current waveform shown in part (A) of figure 2-63, the polarity and amplitude is the same at any two points separated by any whole number of wavelengths. There is a polarity difference of 180 degrees at any two points that are separated by a distance of one-half wavelength or any odd multiple thereof.

If the character of the line changes abruptly (for example, to an open end as shown in part (B) of figure 2-63), the current wave is reflected from the open end and travels back along the line. Point A represents the open end of the conductor. As the incident wave reaches the end of the line (point I), it is immediately reflected back from point R in the direction shown by the arrows that conform to the reflected wave. At the open end the reflected wave is of opposite polarity, but equal in amplitude, to the incident wave; hence, the currents represented by the waveforms cancel out to zero. At a point one-fourth wavelength from the open end, represented by point B, the incident wave and the reflected wave are of the same polarity and amplitude and the currents add together. At a point one-half wavelength from the open end, represented by point C, the incident and the reflected waves again cancel out to zero. Thereafter, at points (B, D, F, etc.) which are odd multiples of quarter wavelengths from the open end, maximum values of current occur; and at points (A, C, E, etc.) which are even multiples of quarter wavelengths from the open end, minimum values of current occur. This phenomenon is known as standing waves. Standing waves are the result of load mismatch and can be changed only by changing the terminating resistance. The points of minimum current are known as nodes; the points of maximum current are known as loops (or antinodes). If a current-measuring device is moved along a wire on which standing waves exist, the positions of the current nodes or loops can easily be located. The voltage along the line also forms standing waves, but reaches its maximum values when the current is minimum, and vice versa.

(*a*) TRANSMISSION LINE TERMINATED IN A CAPACITIVE REACTANCE.— If a transmission line is terminated in a capacitive reactance equal to its characteristic impedance, the distribution of standing waves is essentially the same as that on a transmission line whose termination is open. In both cases, the nearest peak to the terminated end is a current peak. In the case of the line terminated in a capacitive reactance, the current peak is closer to the termination; in other words, it is less than a quarter-wavelength removed from the terminated end. Intermediate values of capacitive reactance would cause proportionate values of standing-wave displacement along a transmission line.

(*b*) TRANSMISSION LINE TERMINATED IN AN INDUCTIVE REACTANCE.— If a transmission line is terminated in an inductive reactance equal to its characteristic impedance, the distribution of standing waves is essentially the same as that on a transmission line whose termination is short-circuited. In both cases, the nearest peak to the terminated end is a voltage peak. However, in the case of the line terminated in an inductive reactance, the voltage peak is shifted closer to the termination. Intermediate values of inductive reactance would cause proportionate values of standing-wave displacement along the transmission line.

(*c*) STANDING-WAVE RATIO. — The ratio of the value of current (or voltage) at a loop to the value at a node is called the standing-wave ratio (SWR). This standing-wave ratio depends upon the ratio of the resistance of the load (pure resistance) connected to the output end of the line, or termination, to the characteristic impedance of the line itself. It is expressed as,

$$SWR = \frac{Z_0}{Z_r} \text{ or } \frac{Z_r}{Z_0}$$

where Z_o is the characteristic impedance of the line and Z_r is the terminating resistance (pure resistance). The formula is given two ways because it is customary to place the larger number in the numerator to make a whole number, rather than a fraction.

A transmission line terminated in a pure resistance equal to its characteristic impedance will normally have no reflections or standing waves. This type of line is nonresonant and may be of any reasonable length. If a transmission line does have standing waves, it is resonant, and its terminating impedance will be affected by the length of the line. Because of this fact, a resonant transmission line may be used for transforming a given impedance into some other value, merely by terminating the transmission line at the desired impedance point. Transmission lines which are not terminated in a purely resistive load react in the manner described in paragraphs 2-10.*a.*(2)-(*a*) and 2-10.*a.*(2)(*b*).

b. MEASUREMENTS UTILIZING STANDING WAVES.—For purposes of repair (troubleshooting), preventive maintenance, checking, and making adjustments, standing-wave-ratio measurements are frequently utilized. On some equipments, or systems, it is more practical to measure the voltage than the current; in this case the ratio is referred to as the voltage-standing-wave ratio (VSWR). A detailed discussion of microwave measurements utilizing VSWR is provided in Section 3 in the paragraph titled RADAR TESTING —OVER-ALL SYSTEM TECHNIQUES.

The standing-wave ratio provides a direct indication of the degree of mismatch along a transmission line of a feed system; it is also used in the measurement of the impedance involved (Smith Chart).

Wavelength (or frequency) can also be measured by using the standing waves which exist on a line.

(1) SWR MEASUREMENTS.—Voltage (or current) distribution along a transmission line provides an effective means of checking and testing the operation of a transmission line between the transmitter or signal source and the antenna or load. A number of methods and test equipments may be used for indicating the voltage (or current) distribution along a transmission line. An open transmission line is accessible for coupling to a sensitive wavemeter, a grid-dip meter, or any type of test equipment capable of measuring r-f voltage amplitude.

Coaxial cable and waveguides are employed on the higher frequencies because of lower skin effect losses. Because of their construction, the previously mentioned methods for measuring voltage (or current) and standing waves cannot be employed. To gain access to the interior of the

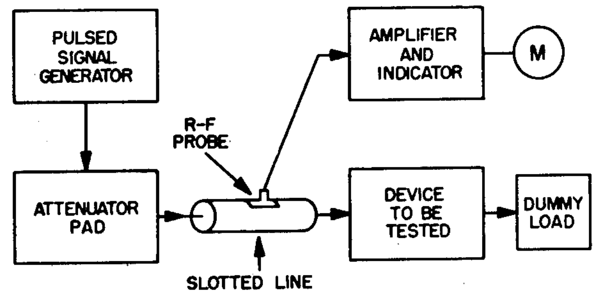


Figure 2-64. SWR Test Setup for Checking Transmission Line Components

waveguide or to the center conductor of the coaxial cable, a unidirectional or bidirectional coupler is inserted into the transmission line. The coupler has a slot into which an r-f probe is inserted, and a method is provided for positioning this probe with respect to directivity and location. When in use, the coupler becomes part of the waveguide or coaxial cable, and the probe is varied as to position and directivity as instructed in paragraph 3-11.*b.*(2). The standing-wave ratio is calculated by measuring the points of maximum and minimum current (or voltage) and dividing the smaller quantity into the larger.

Testing of the individual parts of the transmission line of a system may be required in some cases to determine the cause of a high standing-wave ratio. A test setup for making tests of this kind is shown in figure 2-64. The r-f source is a pulsed signal generator. An attenuator pad is used in series with the generator output to provide attenuation and also to isolate the generator from the rest of the equipment. With this setup, the VSWR of the part being tested may be checked at any frequency within the range of the generator, and any adjustments provided on the part can be set at any specified frequency.

(*a*) IMPEDANCE MEASUREMENT USING SWR.—If a transmission line is terminated in a pure resistive load the same value as the characteristic impedance of the line, the line appears to be infinitely long and there are no standing waves on the transmission line. The input impedance of this line is then the characteristic impedance of the transmission line. If the transmission line is not terminated in the proper load, the input impedance is no longer that of the characteristic impedance of the line, but will have a wide range of values.

The length of transmission line will have no effect upon the standing-wave ratio but will affect the input and output termination impedance. If the line length is such that standing waves cause the voltage at the input terminals to be high and the current low, then the input impedance is higher than the characteristic impedance of the transmission line, since impedance is simply the

ratio of voltage to current. Conversely, low voltage and high current at the input terminals mean that the input impedance is lower than the characteristic impedance of the transmission line. The higher the standing-wave ratio on the transmission line, the greater the range of input impedance values when the line length is varied. In addition to input impedance changes with variations in line length, standing waves also cause the input impedance to contain a reactance and resistance, even though the load itself is a pure resistance. To locate the high-voltage points along a transmission line, refer to paragraphs 2-10. *b.*-(2) and 3-4.*g*.

The fact that the input impedance of a line is dependent upon the standing-wave ratio and line length can be used to advantage when impedance matching or transformation is required. The impedance of a point one-half wavelength away from the input terminals of a transmission line is exactly the same as at the output terminals of this line. This is true at all integral multiples of a half wavelength and for all standing-wave ratios. Such a line may be used to transfer the impedance to a new location without changing its value.

When a transmission line is a quarter wavelength long, or an odd multiple of a quarter wavelength, the load impedance is inverted. That is, if the current is low and the voltage high at the load, the input impedance will be such as to require high current and low voltage. In this manner, the transmission line acts as a transformer, and the relationship between the load impedance and the input impedance may be expressed as:

$$Z_s = \frac{Z_o^2}{Z_r}$$

where Z_s is the impedance looking into the line (the line length being an odd multiple of one-quarter wavelength); Z_r, the impedance of the load (it must be a pure resistance); and Z_o, the characteristic impedance of the transmission line. Given another way:

$$Z_o = \sqrt{Z_s Z_r}$$

Thus two different values of impedance may be connected by a quarter-wave length of transmission line having a characteristic impedance equal to the square root of their product.

(2) WAVELENGTH (OR FREQUENCY) MEASUREMENT.—For the Lecher-wire method of wavelength (or frequency) measurement, refer to paragraph 2-6.*d.*(2).

Another method of measuring wavelength makes use of a slotted-line section and an r-f probe. In this method the spacing between two minimum points is measured, and the value obtained is divided by the propagation factor for the slotted line as specified by the manufacturer. The result is the length of one-half wave in free space. The wavelength may be converted into frequency, but the resultant accuracy is poor.

2-11. SIGNAL GENERATORS—ALIGNMENT OF TUNED CIRCUITS.

A signal generator is a test equipment which generates an a-c signal that is suitable for test purposes. It is in effect a small radio transmitter which can be constructed to generate a signal of any desired frequency. The generated signal may be modulated or unmodulated, and is used for the following tests or checks: alignment of tuned circuits, dynamic trouble-shooting (signal tracing), sensitivity measurements, field-intensity measurements, and approximate frequency measurements. The use mentioned last is limited because the signal generator is not a frequency meter and cannot be relied upon as a frequency standard. The signal generator is used principally in the alignment of tuned circuits.

Signal generators, classified according to frequency, are of two types — audio-frequency or radio-frequency. A-F generators, which are sometimes called audio oscillators, are capable of producing signals whose frequencies range from 20 to 20,000 cycles per second. R-F generators provide practical outputs ranging from 10,000 cycles per second to about 10,000 megacycles. However, no single generator completely covers all of the existing r-f ranges. Various r-f generators are available covering specified portions of the r-f spectrum; many of these also have an audio output which is separately available through a front panel jack (frequencies of 400 and/or 1000 cps are generally provided).

The shape of the output waveform permits a further classification of a-f and r-f generators. A-F generators are subdivided into sine-wave and square-wave or pulse output generators. R-F generators have either pure r-f, AM (amplitude-modulated), FM (frequency-modulated), or pulse-modulated outputs. At this point the technician should already be familiar with AM and FM. In pulse modulation the r-f output is interrupted, usually at an audio rate.

a. AUDIO-FREQUENCY SIGNAL GENERATOR.—Tests and measurements made on many types of a-f equipment, such as amplifiers, modulators, and other voice-frequency apparatus, require a source of controlled audio-frequency oscillation usually with very little or no harmonic content. The frequency range required generally covers 20 to 20,000 cycles per second; however, some audio oscillators have ranges up to 200,000 cycles per second. At these frequencies few of the basic oscillator circuits are practical, principally because of the large size and expense of the inductive and capacitive components necessary for the tuned circuits. Therefore, special types of

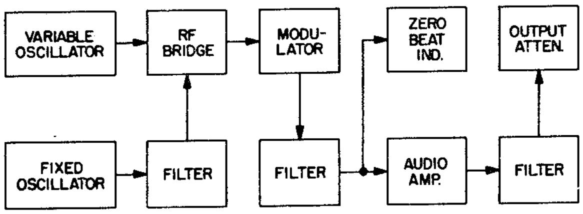


Figure 2-65. ***Block Diagram of a Typical Audio-Frequency Signal Generator***

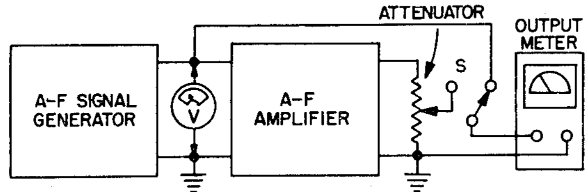


Figure 2-66. ***Test Setup for Sine-Wave Frequency-Response Check of an A-F Amplifier***

audio-oscillator stages are used to provide signals for the required amplitude and frequency. These circuits generally utilize resistance-capacitance (R-C) oscillators and beat-frequency oscillators.

The R-C oscillator provides audio frequencies which are more easily controlled by varying the capacitance rather than the resistance. The change of frequency which can be produced by this method is limited; therefore, it is often necessary to cover the desired frequency range in several steps. This is accomplished by changing either, or both, the resistance and capacitance values. The beat-frequency type of a-f generator, of which the SG-42/URM is representative, will be discussed in the following paragraph.

(1) BASIC OPERATION OF TYPICAL A-F GENERATOR. — The beat-frequency (or heterodyne) oscillator is a common type found in a-f generators. Figure 2-65 shows, in block-diagram form, the circuits comprising a typical a-f generator. Use is made of the difference frequencies resulting from the heterodyning of a fixed-frequency (250-kc) r-f oscillator with a variable-frequency (235 to 250-kc) r-f oscillator of stable characteristics although the possibility of "drift" is still present. The two oscillators are isolated from each other by shielding and by use of a buffer amplifier, which prevents "pull in" of either oscillator at low audio frequencies. Adjustments are provided so that zero beat between the two oscillators can be made to occur at zero dial reading. Since these adjustments are made without auxiliary equipment, the generator is practically self-calibrating. The output frequency is affected very little by changing line voltage, but the output voltage varies in almost direct proportion to such changes. The output waveform is a sine wave.

(2) SINE-WAVE OUTPUT APPLICATIONS.—Among the many applications which utilize sine-wave a-f signals, a few are: the measurement of output power, the measurement of amplification or gain, the checking of amplifier frequency response, the determination of phase shift and distortion characteristics of a-f amplifiers, and the supplying of audio modulation to r-f signal generators.

(*a*) A-F AMPLIFIER FREQUENCY-RESPONSE CHECK.—Since the frequency response of an audio amplifier is essentially a plot of many individual values of gain versus frequency, any basic method used for measuring gain could be utilized. However, the task is considerably simplified and the resulting accuracy improved by using the circuit arrangement shown in figure 2-66. After a reference frequency (either 400, 500, or 1000 cycles) is established, the sensitivity of the output meter is adjusted so that the meter reads the input voltage necessary to produce a specified output voltage. At this point the attenuator is adjusted so that, when switch S is operated, both the input and the output voltage readings coincide at the reference frequency. As the frequency of the input voltage is varied, the resulting changes in output voltage above or below the reference level can be plotted to provide an accurate frequency-response curve of the a-f amplifier under test.

(3) SQUARE-WAVE OUTPUT. — One method of producing square waves utilizes sine waves which are generated in the usual way and then fed to an amplifier that is driven to plate-current saturation on the positive half-cycle of the sine wave and to cutoff on the negative half-cycle. This causes the peaks on the sine waves to be cut off at the top and bottom, and the resulting output is essentially a square wave. A square wave is a complex wave extremely rich in harmonic content. When a square wave is fed to an amplifier, these harmonics are altered in phase and amplitude. These changes alter the waveform at the output of the amplifier. For a discussion of waveform distortion, refer to paragraph 2-8.*c.*(1).

(*a*) APPLICATION OF SQUARE-WAVE OUTPUT.—Square waves have a wide use in the fast and accurate determination of the reproductive faithfulness of a-f and video amplifiers. The use of square waves in checking amplifier frequency response reveals information about the phase characteristics of the amplifier which a sine-wave response check does not disclose.

1. A-F AND VIDEO-AMPLIFIER FREQUENCY-RESPONSE CHECK. — To make an a-f amplifier frequency-response check, connect the amplifier as shown in part (A) of figure 2-67. With the square-wave generator set to deliver the lowest frequency the amplifier is required to pass,

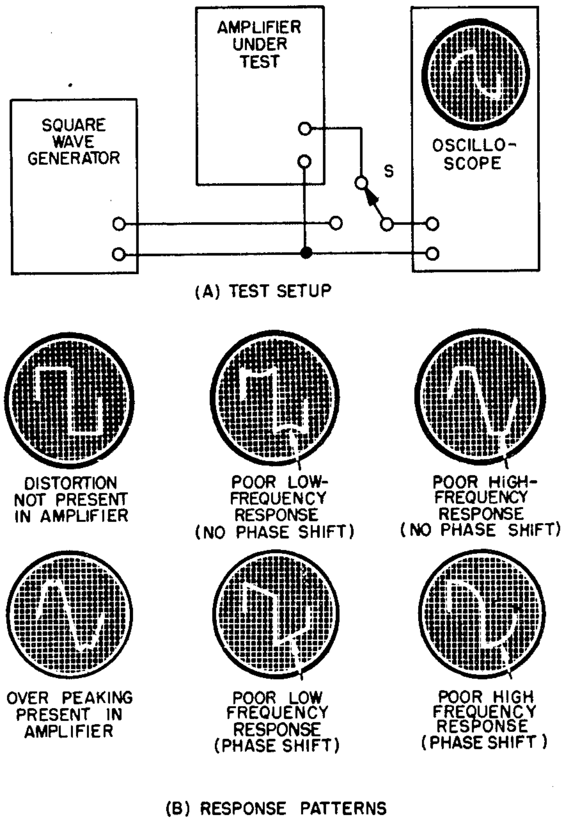


Figure 2-67. Square-Wave Frequency-Response Check of an A-F or Video Amplifier

throw switch S so that the generator output waveform appears on the screen of the oscilloscope. Adjust the oscilloscope controls to provide the best waveshape. (For discussion of the waveform distortion introduced by an oscilloscope, refer to paragraph 2-8.*c*.) Throw switch S to the amplifier output. The resulting pattern viewed on the oscilloscope may be distorted in several different ways depending on which harmonic components of the input square wave are discriminated against either in amplitude or in time (phase). Part (B) of figure 2-67 shows several common response patterns encountered in checking amplifier response. Next, increase the output frequency of the square-wave generator, and repeat the procedure listed above until the complete pass band of the amplifier has been covered and the resulting patterns examined.

The frequency response of a video amplifier is checked in the same manner as an a-f amplifier with the exception that only square-wave output frequencies of 30 cycles and 300 kc are used. If the response patterns show negligible distortion, the response of the video amplifier may be considered to extend as high as 15 times the fundamental frequency of the square wave.

(4) CALIBRATION.—Two convenient frequency standards are available for the calibration of a-f signal generators: the 440 and 600-cycle tone modulations of the Bureau of Standards' station WWV (refer to paragraph 2-7.*a*.(5)) and the power-line frequency (usually 60 cycles). The frequencies at several points on the generator dial are checked against the selected standard by means of Lissajous figures observed on the screen of an oscilloscope. For a discussion concerning frequency comparison with Lissajous figures, refer to paragraph 2-8.*b*.

b. RADIO-FREQUENCY SIGNAL GENERATORS.—Radio-frequency signal generators comprise a rather large and very useful class of test equipments. Because of the extremely wide frequency range in the r-f region of the spectrum, many signal generators with different r-f ranges, as well as other instrument refinements, are available to the technician. The following general analysis of r-f signal generators is provided to acquaint the technician with the principal circuits that are used in these generators.

(1) GENERAL CIRCUIT CHARACTERISTICS.—In addition to the required power supply, the circuits common to most r-f signal generators are the oscillator circuit, the modulator circuit, and the output circuit.

(*a*) THE OSCILLATOR CIRCUIT.—The oscillator has as its function the emission of a signal the frequency of which can be accurately set to any point in the designed frequency range. The type of oscillator used depends on the range of frequencies required. It may have as its resonant circuit a simple coil and capacitor (LC), a tuned line, a tuned cavity, or any of the various specialized types designed for microwave frequencies.

(*b*) THE MODULATOR CIRCUIT.—The modulating circuit functions to change the r-f output in accordance with the successive instantaneous voltage values of the audio or video modulating signal. For a particular generator the modulating signal may be provided by an internal source, by an external source, or by both depending upon the design of the instrument. A meter is often included to indicate (and to permit control of) the percentage of modulation. The form the modulating signal may take depends upon the application of the particular signal generator. It may be a sine wave, a square wave, or a pulse. Some instruments have special provisions for pulse modulation, which permits the r-f signal to be pulsed over a wide range of pulse repetition frequencies (prf) and at various pulse widths. An external synchronizing pulse may be used to initiate a generator pulse which, in some cases, may be delayed as long as 300 microseconds after initiation. In an AM signal generator an audio oscillator is generally employed to modulate an r-f oscillator. Frequency shift of the r-f oscilla-

tor may occur when an oscillator is directly modulated. For this reason the modulation percentage is generally kept at a low figure, usually about 30 percent. In FM or sweep generators, excessive frequency deviation (sweep) may produce a type of AM modulation of the r-f signal. Although not always the case, this type of modulation may not be noticeable when the FM signal is fed to a receiver with limiter action. For this reason, and to avoid distortion in scope presentations, only sufficient deviation (sweep) should be provided to accomplish the purpose.

(*c*) THE OUTPUT CIRCUIT.—The output circuit contains a calibrated attenuator and often an output-level meter. The output-level meter, which permits accurate control of the output of the oscillator, indicates arbitrary values of oscillator output. The attenuator selects the amount of this output that is required, and is usually calibrated in terms of microvolts. When the output-level meter is adjusted to unity (1), the attenuator provides a direct reading in microvolts. At other output-level-meter readings, the decimal value of the reading is multiplied by the attenuator reading to give the microvolt output.

(2) OPERATION OF A TYPICAL R-F (CW OR AM) GENERATOR.—The typical r-f signal generator (of which the AN/URM-25 is representative) shown in figure 2-68, contains the following circuits: oscillator, buffer, output, crystal calibrator, modulation oscillator, and VTVM measuring circuit. Included also are the attenuator circuits and the required power supply circuits.

The r-f oscillator generates an r-f signal of adjustable frequency which is applied to the output amplifier stage through the buffer stage. A modulation oscillator, which generates an audio voltage (400 or 1000 cycles) modulates the output stage, the audio signal being applied at the control grid. The modulated signal is then fed to the step attenuator circuit, where the desired amplitude is selected. A vacuum-tube voltmeter is provided for measuring the carrier output. Provision is also made for external modulation. The output of the modulation oscillator is available for external use. A crystal calibrating circuit is also provided to calibrate the r-f frequency from 1 mc to 50 mc. Use of this calibrator circuit limits the frequency error of the AN/URM-25 to less than 0.05% at these frequencies.

In measurements of amplifier sensitivity careful attention must be given to matching the impedance of the connecting cables when frequencies above 5 megacycles are involved. Directions for properly terminating coaxial lines that are connected to loads are given in instruction books and should be followed closely when power measurements are made. Instructions usually accompany most signal generators for calibration by means of a heterodyne frequency meter. Signal generators are rather unstable and should not be relied upon for the setting of receivers or transmitters on communication frequencies.

(3) FREQUENCY-MODULATED SIGNAL GENERATORS.—Various types of frequency-modulated signal generators are available to the technician; however, these generators are restricted to specialized applications with the exception of that type known as a sweep generator. The following general analysis of FM signal generators is given to provide the technician with basic information pertinent to all types of FM generators. Sweep generators will be discussed separately following the general analysis.

(*a*) GENERAL ANALYSIS. — An FM signal is one in which the output frequency varies above and below a center frequency. The over-all frequency variation is known as the frequency swing (or deviation), and the rate at which this swing recurs is controllable at any audio (or video) frequency rate for which the generator has been designed. The frequency change of the output may be accomplished by the mechanical variation of either the capacitance or inductance of the oscillator circuit, or the use of a reactance tube connected to the oscillator circuit. In the latter case, changes of the voltage impressed on the grid of the reactance tube change the amount of reactance introduced into the oscillator tuned circuit, and as a result cause the output frequency to change. The frequency of the signal on the grid of the reactance tube thereby controls the rate of frequency deviation, and the amplitude of the signal voltage controls the amount of the deviation.

(*b*) SWEEP GENERATORS. — A sweep generator is a form of an FM signal generator the carrier deviation of which is adjustable by means of a sweep-width control; however, the sweep generator differs from the ordinary FM signal generator in that the rate of carrier deviation is generally maintained at a fixed frequency. The voltage used to effect the deviation may be either a sine wave (very common) or a sawtooth waveform. Since an oscilloscope is used to observe the patterns which are formed when the passband of interest is swept by this type of generator, the oscilloscope time base must utilize (or be synchronized with) the same waveform used to produce the deviation. The horizontal (or time) axis of the pattern then represents the instantaneous frequency of the generator output, while the vertical axis shows the response characteristic of the circuit under test for each frequency. Sweep generators are widely used for the observation of response characteristics and the visual alignment of tuned circuits.

Deviation of the carrier may be accomplished either electromechanically or electronically. The

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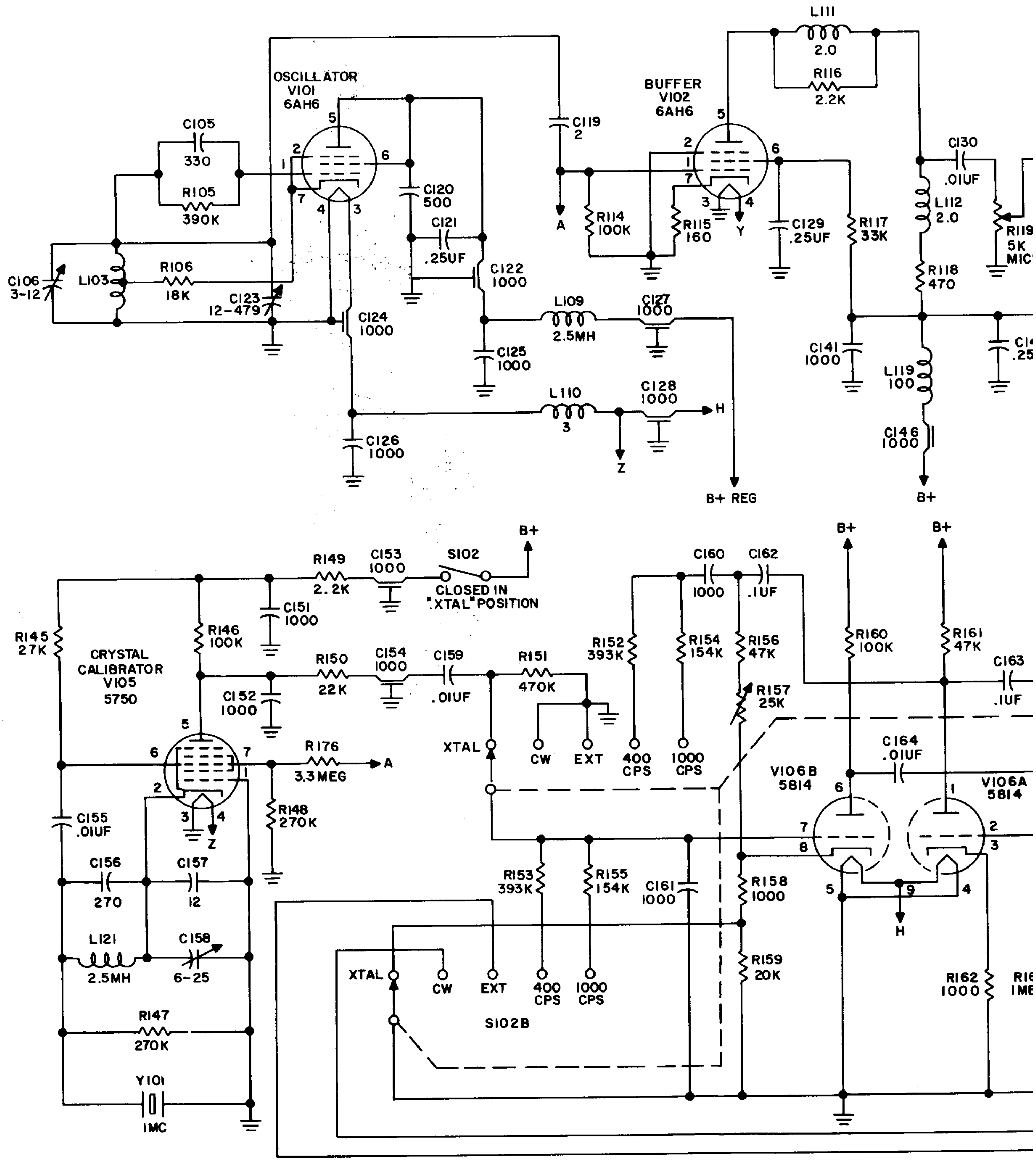
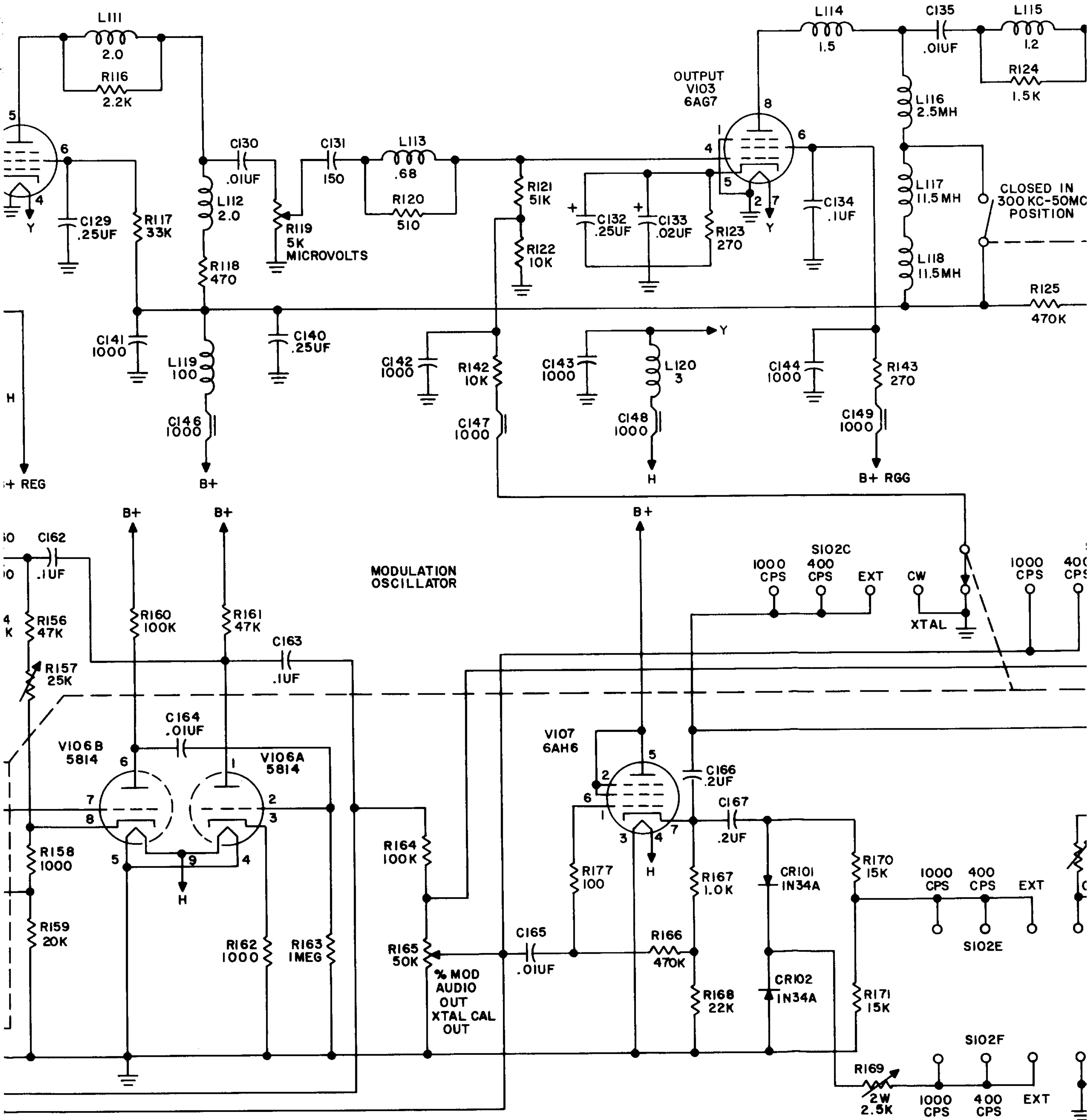

OSCILLATOR
V101
6AH6
BUFFER
V102
6AH6
L111
2.0
R116
2.2K
C105
330
R105
390K
C119
2
C130
.01UF
C120
500
C121
.25UF
R114
100K
R115
160
C129
.25UF
R117
33K
L112
2.0
R119
5K
C106
3-12
L103
R106
18K
C123
12-479
C122
1000
C124
1000
L109
2.5MH
C127
1000
R118
470
C141
1000
C125
1000
L119
100
L110
3
C128
1000
C146
1000
C126
1000
B+ REG
B+
A
Y
Z
H
R149
2.2K
C153
1000
S102
CLOSED IN
"XTAL" POSITION
C160
1000
C162
.1UF
R145
27K
CRYSTAL
CALIBRATOR
V105
5750
R146
100K
C151
1000
R150
22K
C154
1000
C159
.01UF
R151
470K
R152
393K
R154
154K
R156
47K
R157
25K
R160
100K
R161
47K
C163
.1UF
C152
1000
XTAL
CW
EXT
400
CPS
1000
CPS
C164
.01UF
V106B
5814
V106A
5814
R176
3.3MEG
R148
270K
C155
.01UF
C156
270
C157
12
R153
393K
R155
154K
C161
1000
R158
1000
L121
2.5MH
C158
6-25
R159
20K
R162
1000
S102B
R147
270K
Y101
1MC

2



L111
2.0
R116
2.2K
C129
.25UF
R117
33K
C130
.01UF
L112
2.0
R118
470
R119
5K
MICROVOLTS
C131
150
L113
.68
R120
510
R121
51K
R122
10K
OUTPUT
V103
6AG7
C132
.25UF
C133
.02UF
R123
270
C134
.1UF
L114
1.5
C135
.01UF
L115
1.2
R124
1.5K
L116
2.5MH
L117
11.5MH
L118
11.5MH
CLOSED IN
300 KC-50MC
POSITION
R125
470K
C141
1000
L119
100
C140
.25UF
C146
1000
B+ REG
B+
C142
1000
R142
10K
C147
1000
C143
1000
L120
3
C148
1000
H
C144
1000
R143
270
C149
1000
B+ RGG
MODULATION
OSCILLATOR
C162
.1UF
R156
47K
R157
25K
R160
100K
R161
47K
C163
.1UF
C164
.01UF
V106B
5814
V106A
5814
R158
1000
R159
20K
R162
1000
R163
1MEG
R164
100K
R165
50K
% MOD
AUDIO
OUT
XTAL CAL
OUT
C165
.01UF
V107
6AH6
R177
100
C166
.2UF
C167
.2UF
R166
470K
R167
1.0K
R168
22K
CR101
1N34A
CR102
1N34A
R170
15K
R171
15K
R169
2W
2.5K
S102C
1000
CPS
400
CPS
EXT
CW
XTAL
S102E
S102F

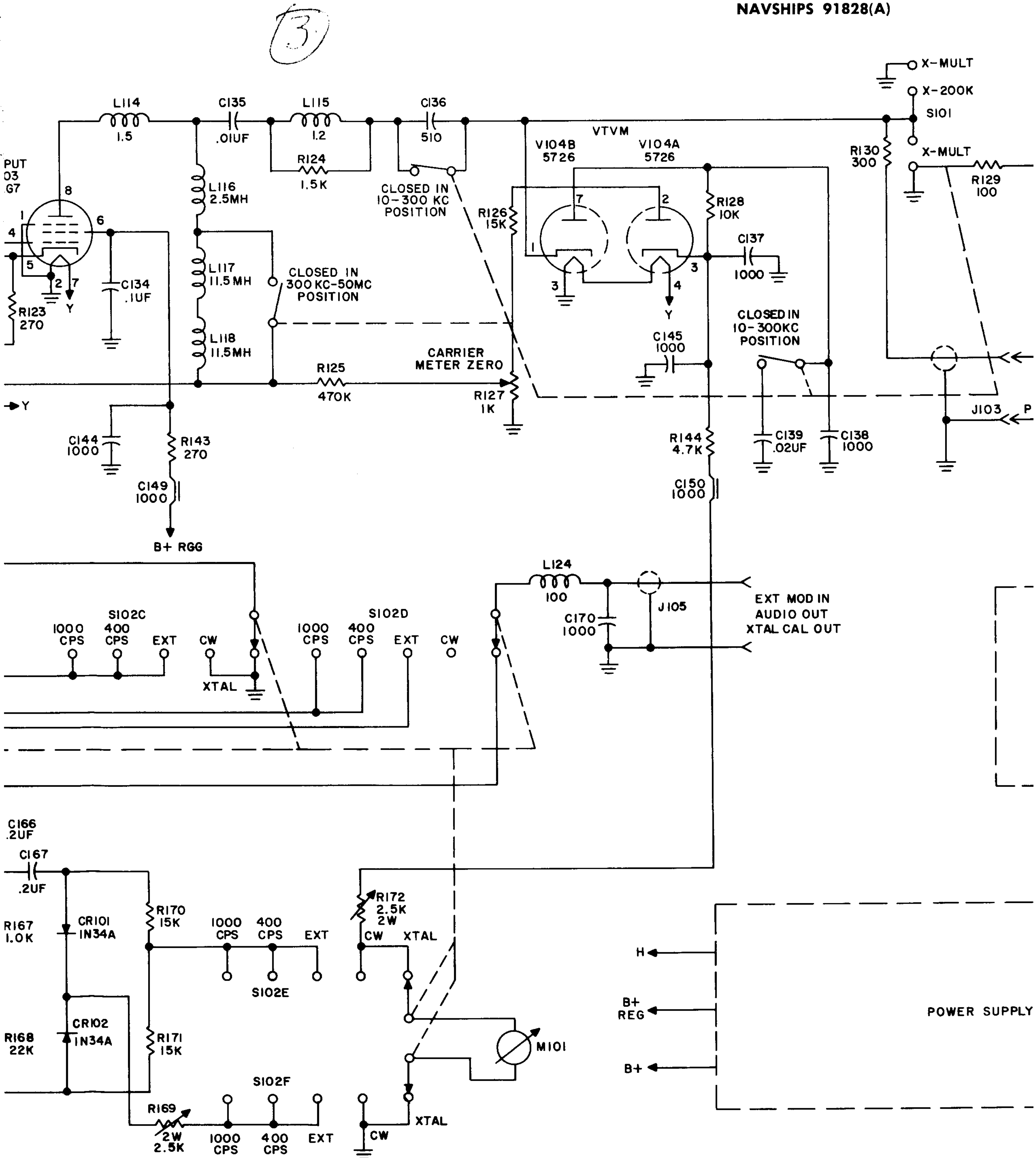
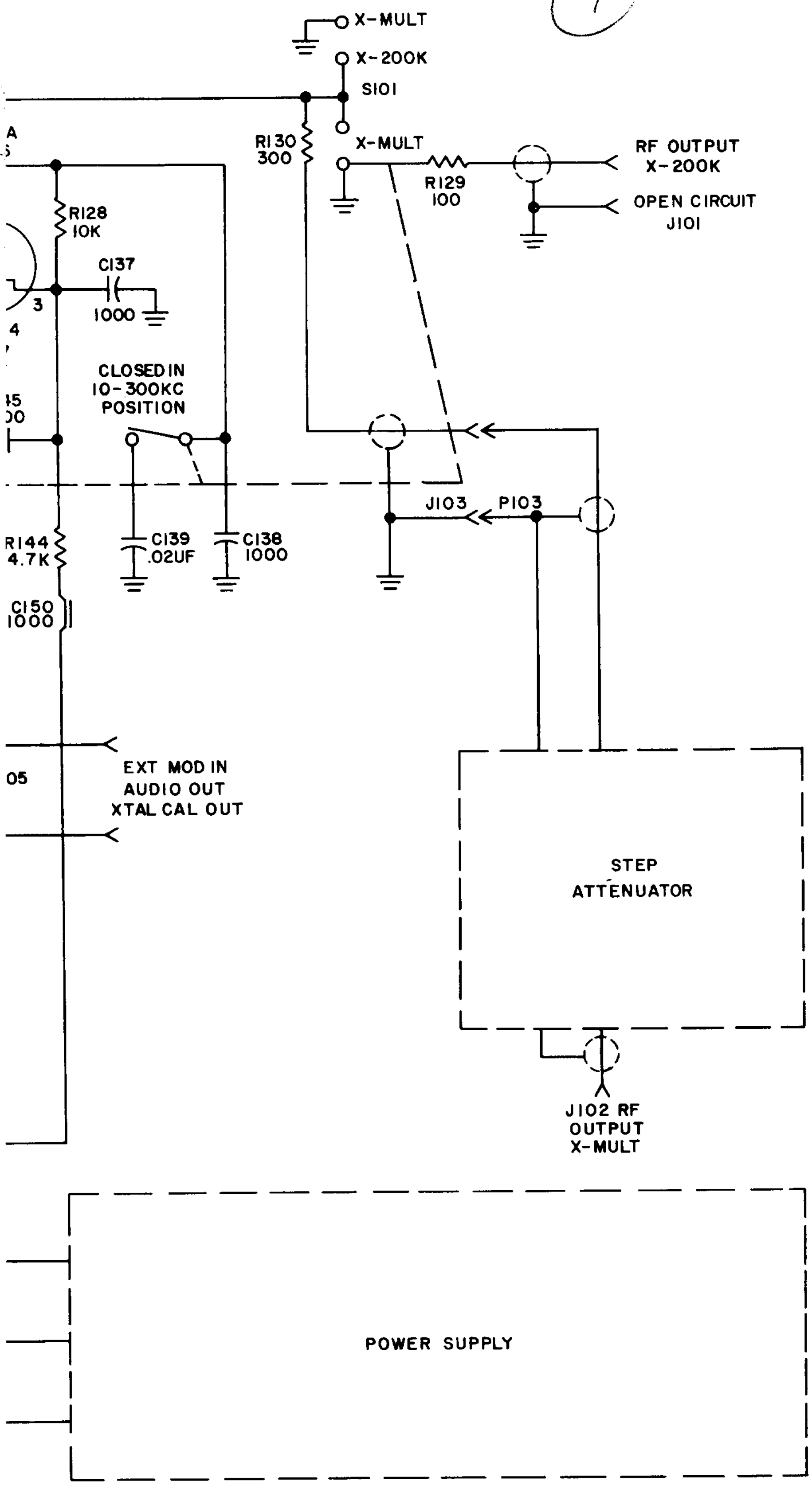


Figure 2-68. Simplified Schematic Diagram of a Typical R-F (AM or CW) S



l Schematic Diagram of a Typical R-F (AM or CW) Signal Generator

electromechanical method consists of mechanically varying the capacitance or the inductance of the oscillator tank circuit, causing the frequency to vary accordingly. The electronic method makes use of a reactance-tube modulator.

A sweep generator produces patterns containing a considerable number of instantaneous frequencies. It is necessary to introduce marker signals, which are superimposed on the trace, in order to orient pass-band characteristics (or center frequency) of the circuit under test with respect to frequency. The circuit which produces the marker signals may be an integral part of the instrument, or the marker signals may be supplied from an external source such as an AM signal generator coupled to the circuit being tested.

1. ELECTROMECHANICAL MODULATOR.—The simplest form of modulator is a rotating, motor-driven capacitor which is connected across the tank circuit of the oscillator in the signal generator. The frequency (rate) at which the signal output is swept, or modulated, is dependent upon the speed of the motor. In practice the frequency is usually maintained at approximately 60 cycles per second.

This type of modulator has a rather serious disadvantage. The amount of deviation of the output signal changes whenever the operating frequency of the oscillator is varied, and cannot be controlled except by changing the value of the rotating capacitor. This fault is overcome by the use of two oscillators: one having the rotating capacitor across its tank circuit and designed to operate at a fixed center frequency, and the other having a variable-frequency output to permit tuning. The outputs of these oscillators are heterodyned together in a mixer stage, to produce the desired frequency-swept signal in the form of a sum or difference-frequency signal. Since the center frequency of the sweep-generating oscillator is fixed and tuning takes place in the other oscillator, the deviation rate of the output signal of the sweep generator remains constant regardless of the tuned frequency in use.

2. REACTANCE-TUBE MODULATOR.—Most frequency-swept signal generators now being manufactured use a reactance-tube method of modulation. This method is more flexible, lighter, and more compact than the rotating capacitor. The reactance tube and its associated components are connected across the tank circuit of the oscillator in the signal generator. In many cases the a-c power line, which provides an excellent oscilloscope synchronizing medium, is coupled to the grid of the reactance tube to control the rate of the sweep. The reactance-tube modulator has an advantage over electromechanical modulators in the respect that it can be excited by an external variable a-f signal generator, whereas the electromechanical modulator is usually limited to single-frequency operation.

3. OSCILLOSCOPE TIME AXIS CALIBRATION—MARKER PIPS.—Two methods of calibrating the oscilloscope time axis in terms of frequency are in common use. One method utilizes a succession of fixed marker pips which are superimposed on the oscilloscope pattern by applying signals suitably spaced in frequency to the input of the vertical amplifier or to the cathode-ray-tube grid. In some cases these marker frequencies are produced by the "ringing" of a succession of tuned circuits by the FM oscillator itself, or by a separate oscillator of the multivibrator type which provides a continuous series of harmonics spaced at convenient intervals. The other method of sweep-frequency calibration makes use of a separate variable-frequency oscillator which is manually tuned by means of an accurately calibrated dial. This method produces a single movable pip, which identifies the frequency associated with any particular point on the oscilloscope trace.

(4) PULSE-MODULATED SIGNAL GENERATORS.—A pulse-modulated signal generator is similar to the conventional r-f signal generator with the exception that its output consists of r-f energy in the form of pulses which occur at an audio rate. Controls are provided to vary the pulse width (time of each pulse) and the repetition rate (number of pulses per second). A common application of pulse-modulated generators is found in the checking of receiver performance of many radar systems, which employ a pulse-type emission.

(*a*) GENERAL ANALYSIS.—Pulse-modulated r-f signals are produced by generating a constant r-f carrier by means of a conventional oscillator circuit and feeding this energy to the grid of a mixer stage which has at the same time impressed on its suppressor grid a square wave generated in a separate circuit. The positive half-cycles of the square wave allow the mixer tube to conduct, and the negative half-cycles cut off the tube. During the conduction intervals, the plate current is varied by the r-f signal on the control grid. Therefore, pulses of r-f current, corresponding to the positive half-cycles of the square wave, appear in the mixer plate circuit. The pulses are generally fed to one or more amplifier stages. Pulse time and repetition rate are varied by controls in the square-wave circuit.

(5) CALIBRATION. — R-F signal generators are usually calibrated by one of two methods. The first method uses a crystal-controlled oscillator which is an integral part of the instrument itself. The second method utilizes the accurately

calibrated frequencies generated by a heterodyne frequency meter, or the standard transmissions of the U. S. Bureau of Standards' radio station WWV.

(*a*) INTERNAL. — Many signal generators are equipped with an internal crystal-controlled oscillator. The fundamental frequency and its harmonics provide an accurate means of checking the r-f generator output at several different points on the calibrated dial of the generator by the heterodyne principle of frequency measurement, which produces Lissajous figures on the sereen of an oscilloscope, as described in paragraph 2-8.*b*.(1).

(*b*) EXTERNAL. — Signal generators which are not provided with an internal crystal-controlled oscillator are usually checked and the dial calibrated by means of a heterodyne frequency meter. This method is the same as the method of measuring frequency described in paragraph 2-7.*c*.(2). It is also possible, as was mentioned previously, to use the radio frequencies transmitted by the Bureau of Standards' radio station WWV.

c. ALIGNMENT OF TUNED CIRCUITS. — For most radio purposes, a tuned circuit may be defined as a combination of inductance (L) and capacitance (C) which can be preset or adjusted to produce electrical resonance at a desired frequency. Since it is practically impossible to design equipment in which the major L-C elements conform to very tight resonant frequency tolerances without auxiliary means of adjustment, and since aging of the reactive (L-C) components and changes in other circuit elements (for example, electron tubes) affect the resonant frequency, small additional variable reactive elements are provided in most tuned circuits so that minor adjustments affecting resonance (trimming) can be accomplished.

(1) DEVICES FOR RESONANCE ADJUSTMENT (TRIMMING). — The variable capacitive components employed in Naval equipment for major circuit tuning are usually air-dielectric variable capacitors. These are generally provided with small auxiliary shunt (and sometimes series) capacitors for trimming purposes. Variable inductive components for major tuning and for trimming may make use of cores (slugs) constructed of magnetic material (permeability tuning) and/or cores or "vanes" made of nonmagnetic material (eddy-current tuning). The inductance can also be changed by spreading or crowding the coil turns; by bending a single coil turn away from the rest of the coil; by the use of continuously variable brush-type connections; or by the use of fixed taps (combined with other methods of continuously variable inductive or capacitive trimming).

In general, trimming or circuit alignment may be defined as the process of adjusting the tuned circuits of an electronic equipment (using the adjustable components provided therefor) to produce resonance at such frequencies as may be required or specified for such adjustments. The condition of optimum adjustment may be made evident by the use of a suitable meter or other form of indicator.

In the text to follow, the alignment of the various tuned circuits in a typical superheterodyne receiver will be discussed. The circuits of such a receiver are basically or functionally representative of various types of circuits encountered in radio equipment. Both low-frequency operation (arbitrarily considered as below 30 mc) and high-frequency operation (above 30 mc) will be included. Wave traps, which are used extensively in radio equipment, will also be discussed.

(2) THE SUPERHETERODYNE SYSTEM OF RECEPTION.—A receiver in which the incoming signal is combined with (heterodyned by) a locally generated unmodulated wave so as to convert the signal to a desired new frequency region (intermediate frequency) is generally known as a superheterodyne. The resulting i-f signal is usually amplified and demodulated (detected), and the desired output from the demodulator is then amplified and applied to headphones, loudspeakers, cathode-ray tubes, or other terminal devices which reproduce the intelligence carried by the signal.

(3) ALIGNMENT OF THE SUPERHETERODYNE.—To simplify the discussion of alignment, the superheterodyne will be divided into the following component units: the r-f tuner or preselector (including the heterodyne oscillator), the i-f amplifier, and the demodulator stage. This breakdown describes the simplest form of superheterodyne receiver; actually the heterodyning process may be carried on more than once, resulting in double-conversion, triple-conversion, etc., superheterodyne reception.

(*a*) THE R-F TUNER (PRESELECTOR).—The r-f tuner or preselector of a superheterodyne usually consists of the following elements: (1) an r-f amplifier of one or more stages; (2) the mixer (or first detector); and (3) the "local" or heterodyne oscillator. (The term "converter" is often applied to the combined mixer and oscillator stages, especially when a single tube is used for both functions.) All receivers using the heterodyne principle of operation have one characteristic in common; they generate a fixed-frequency signal (equal to the i-f center frequency) whose frequency is the difference between the frequency generated by the local oscillator and the carrier frequency of the incoming signal which is converted. For best

operation of the receiver, the r-f stage (or stages) should be accurately tuned to the desired signal. The fixed frequency difference between the r-f signal carrier and the heterodyne oscillator must usually be maintained over the entire tuning range of the receiver with a high degree of accuracy. Since a single control is commonly used to tune the r-f stages and the oscillator circuit simultaneously, the variable capacitors or inductors which provide major tuning of these circuits are ganged together. The simultaneous operation of these components requires that the proper frequency relationships of the circuits be maintained throughout each tuning range, or band, and this process is called "tracking." Proper tracking is accomplished practically in several different ways, as described below.

1. TRACKING IN LOW-FREQUENCY OPERATION.—Low-frequency applications (below 30 mc) usually require fairly large variable main-tuning capacitors (about 100 to 1000 $\mu\mu$f). Shunt capacitors (trimmers) are usually provided for all the main-tuning capacitor sections, together with a series capacitor (padder) in the oscillator tank circuit, and sometimes in other circuits as well, to control frequency and to permit satisfactory alignment and tracking. In some cases, the plates of the tuning-capacitor section used in the oscillator tank circuit are shaped ("cut") to produce a variation of capacitance which differs from that of the r-f tuning-capacitor sections, and which is designed to maintain proper oscillator tracking, thus eliminating the need for the oscillator series padder capacitor. Still another method utilizes tank inductances of differing value and physical configuration, which are individually slug-tuned but with ganged control of slug motion. Figure 2-69 shows the simplified circuit of a typical low-frequency preselector which uses shunt trimmers and an oscillator series padder. It should be noted that in most

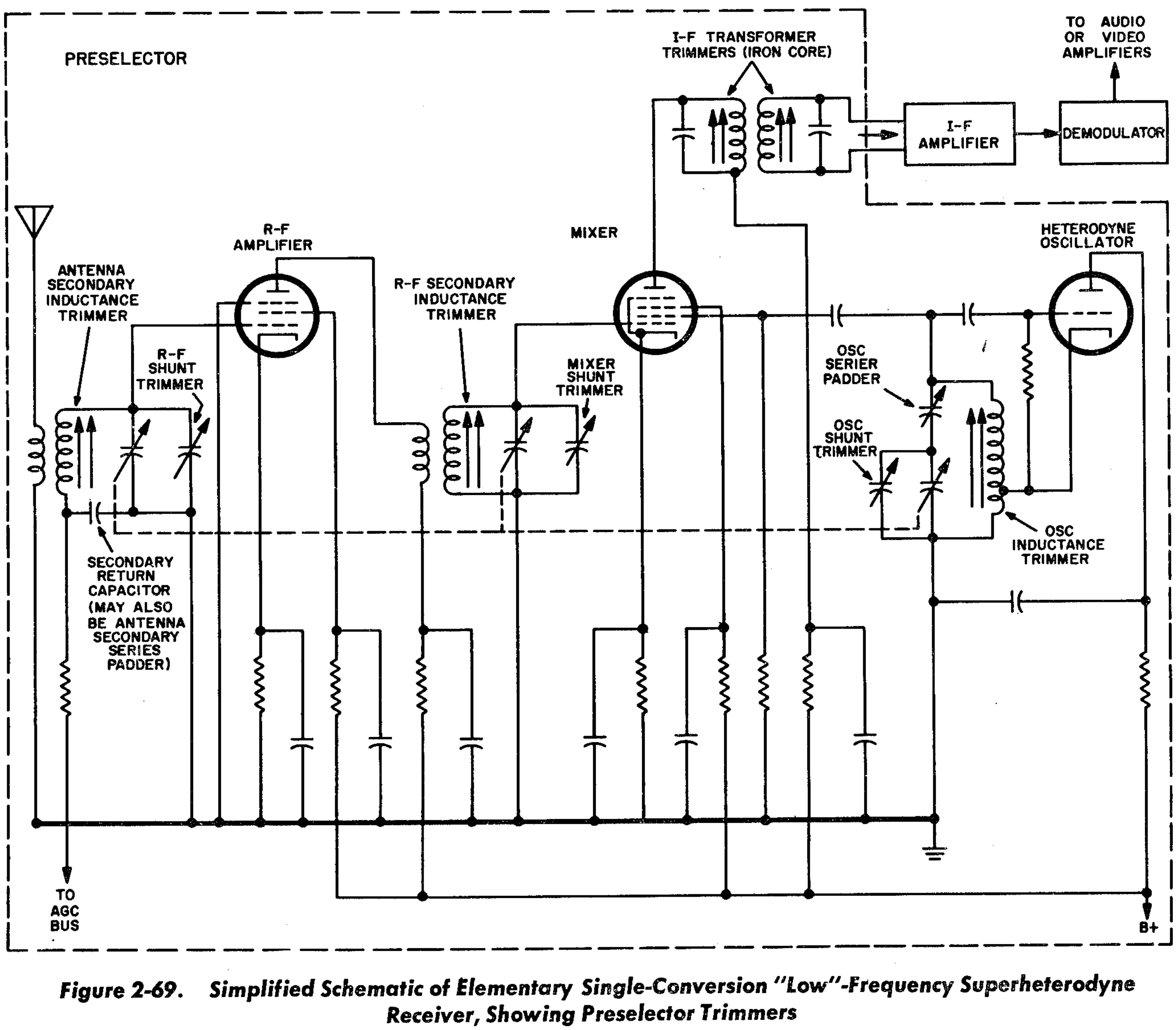


Figure 2-69. Simplified Schematic of Elementary Single-Conversion "Low"-Frequency Superheterodyne Receiver, Showing Preselector Trimmers

equipments employing shunt-capacitance trimmers, adjustment of these trimmers must usually be made at or near the high-frequency (minimum tuning capacitance) end of the tuning range. This is necessary to equalize the differences between circuits, in the form of residual ("stray") capacitance and inductance, at the most critical region in the tuning range. These differences contribute largely to misalignment between circuits, and are most evident at the high-frequency end of the range because at this end the major tuning elements are at minimum value. The series padder trimmers are usually most effective in producing compensation for undesired circuit-to-circuit differences in resonant frequency when adjusted at the low-frequency end of the tuning band.

In some receivers, several bands of tuning are employed to provide greater frequency range. In the higher-frequency bands of some of these receivers, the heterodyne oscillator may operate on the low-frequency instead of the high-frequency side of the received signal. However, the basic problems and techniques of circuit alignment remain about the same for each band. Before attempting to align any complex equipment, it is absolutely essential that the appropriate instruction manual be consulted for the alignment procedure and for the location of the adjustment controls.

2. TRACKING IN HIGH-FREQUENCY OPERATION. — In high-frequency applications (above 30 mc), the components of a tuned circuit may be much smaller, both physically and electrically, than those used in corresponding low-frequency applications, and may assume widely different forms. For instance, deliberate use is sometimes made of residual or stray (wiring and tube) capacitances and lead inductances to form resonant circuits. As a consequence, some of the most important circuit elements may not be apparent in visual inspection.

Some of the VHF-UHF circuit assemblies used in Navy equipment are constructed as self-contained, pre-aligned units which are not designed for correction of alignment in the field. In these units, tuned-circuit tracking and alignment are accomplished entirely at the factory. There are a few tuners of this type that have provisions for some "touch-up" adjustments in field use. However, even these assemblies are designed so that if serious alignment trouble develops, they must be returned to the factory for complete realignment. With units of this general type, it is mandatory that the proper instruction manuals be consulted before any adjustment is attempted.

The problems of circuit alignment and tracking are basically the same, regardless of the frequency of operation. Hence the general information given above for low-frequency circuits will hold (with some variations) for circuit assemblies that are designed for high-frequency use. In all cases where instruction manuals or other pertinent literature are available, they should be studied carefully and the instructions applied, so that the best performance of the equipment may be realized.

(*b*) THE I-F STAGE.—The i-f amplifiers usually provide the greater portion of the selectivity and amplification and are used in that section of a superheterodyne receiver which precedes the demodulator or final detector. The designer's choice of the number and type of stages used for i-f amplification is governed by many factors, involving such considerations as the practicable gain and selectivity of the preselector stages, the desired over-all receiver gain and selectivity, the selectivity ratio, etc.

The intermediate frequencies employed in Navy equipment range from less than 100 kc to over 60 mc. Of various important factors, two particularly influence the choice of the intermediate frequency (or frequencies, in the case of multiple-conversion receivers). These are (1) the over-all receiver selectivity required, and (2) the tolerable value of "image" response. Image response is the degree of acceptance by the r-f stages of an interfering image signal. An image signal is one whose frequency is higher, or lower, than the local-oscillator frequency (higher, if the oscillator frequency is higher than the desired signal frequency; lower, in the opposite case) by an amount equal to the intermediate frequency. The image signal beats with the oscillator signal to produce the same intermediate frequency as that produced by the desired signal. Greater selectivity in terms of kilocycles of weak-signal separation is obtained for a given degree of equipment complexity when a lower intermediate frequency is used. On the other hand, a desired degree of primary image rejection is usually achieved by providing the greatest practicable degree of preconversion selectivity in the r-f tuner together with the highest i-f center frequency feasible. With a high intermediate frequency, there is greater separation between the desired signal and image frequencies, and this greatly improves the image-rejection capability of the receiver. In general, the intermediate center frequency or frequencies are chosen so as to avoid regions in the radio spectrum in which interference from high-power or local transmitters (for example, the transmitters in the AM broadcast band) can be picked up directly by the i-f amplifier stages.

1. LOW-FREQUENCY I-F AMPLIFIERS. — One form of typical low-intermediate-frequency (30 mc or lower) amplifier design employs cascaded r-f pentode tubes, which are cou-

pled by double-tuned-circuit i-f transformers that provide both selectivity and suitable electron-tube plate loading for the necessary amplification. Since transformers of this type are usually designed for considerably less than critical coupling, it is normally feasible to align all the i-f tuned circuits by adjusting them for maximum gain at the center frequency of the i-f pass band. The i-f transformers are usually mounted in small metal cans, and are commonly adjusted by means of screws controlling tank inductance or capacitance. In receivers requiring a broad pass band, stagger-tuning or overcoupling (above critical coupling) of the i-f transformers may be found. Some receivers also incorporate an i-f bandwidth control. This control usually modifies the coupling (and, in some cases, the resistance) of the tuned circuits, generally with some change in i-f gain.

2. HIGH-FREQUENCY I-F AMPLIFIERS.—The i-f stages of radar or intercept receivers offer typical examples of high-intermediate-frequency amplifiers (30 mc and higher). Selectivity and interstage loading may be provided by either single tuned circuits or coupled-circuit transformers. The required pass band (often 1 mc or more) is usually obtained by stagger-tuning of the cascaded single-tuned circuits, or by the use of double-tuned-circuit transformers or equivalent filter networks with suitable Q and coupling. In some cases, circuit Q's may be reduced to desired lower values by the use of shunt resistors across the coils. Slug-core position adjustment is one commonly employed means for aligning the i-f resonant circuits. Acceptor and rejector circuits (wave traps) are provided in some designs to produce additional selectivity or response at particular frequencies (see figure 2-70).

3. LIMITING AMPLIFIERS. — A particular form of i-f amplifier, encountered in some AM receivers and many FM receivers, is designed to operate as an amplitude "limiter." Such a device is a means of reducing or eliminating amplitude variations (including noise-voltage fluctuations) from the i-f signal prior to final detection, while providing amplification of the desired carrier. The limiting effect usually results from electron-tube operation designed to permit the flow of control-grid current and plate-current saturation on signal peaks. Alignment of the tuned circuits of this type of amplifier must usually be done with signal input well below the level at which limiter action begins (the threshold of limiting); otherwise, the changes of output level which are commonly depended on to indicate circuit peaking during trimming will be masked.

(*c*) THE FINAL DETECTOR OR DEMODULATOR.—The purpose of the demodulator is to regain, usually by means of rectification and filtering, as much as possible of the waveform representing the original intelligence impressed on the carrier wave at the transmitter. In an AM receiver, this may be accomplished by any one of several types of detectors. The simple series-diode circuit is most commonly used. The r-f or i-f transformers which drive AM detectors do not, as a rule, have adjustments differing from the preceding circuits for purposes of alignment, and hence will be discussed no further. However, FM and PM (phase modulation) detectors require filter circuits preceding their rectifier elements. These filters, which are frequency and phase responsive and are known as frequency (or phase) discriminator transformers, do require special alignment. The discussion to follow will briefly analyze some typical FM detectors.

1. FM DETECTORS. — FM detectors commonly employ either a composite frequency discriminator transformer, or two entirely separate filters peaked on either side of the carrier frequency, driving a pair of diode rectifiers suitably connected. It is also possible to produce "side-slope" detection with a single side-tuned filter and a rectifier. The composite discriminator transformer consists, in most cases, of an i-f transformer which has a center-tapped secondary winding, sometimes provided with primary and secondary variable-capacitor adjustments for alignment purposes, or designed so as to prevent serious secondary unbalance and change of primary-to-secondary coupling if inductance trimming by slug motion is utilized. The primary and secondary are usually coupled by mutual induction close to the critical-coupling value. In addition, the primary, which serves as the plate load for the driving tube, is connected at its "high" end to the secondary center tap through a capacitor, thereby producing a circuit arrangement resembling a balanced demodulator (see figure 2-71). In some designs, the primary is coupled to the secondary center tap by means of a separate untuned coupling coil.

2. THE FOSTER-SEELEY (FM) DETECTOR. — The Foster-Seeley detector (figure 2-63A), which is widely used for FM and PM signal demodulation, utilizes two diodes, each with a series load resistor, connected in series opposition across the secondary winding of the discriminator transformer. The output voltage available at points $X_1 - X_2$ is the combined series potential appearing across the two load resistors. Since the two diodes are operating in series opposition, the net d-c output potential is zero when the discriminator-primary voltage plus one half of the secondary voltage (which is the combination providing the driving signal for each diode) is the same for both diodes. With a properly aligned

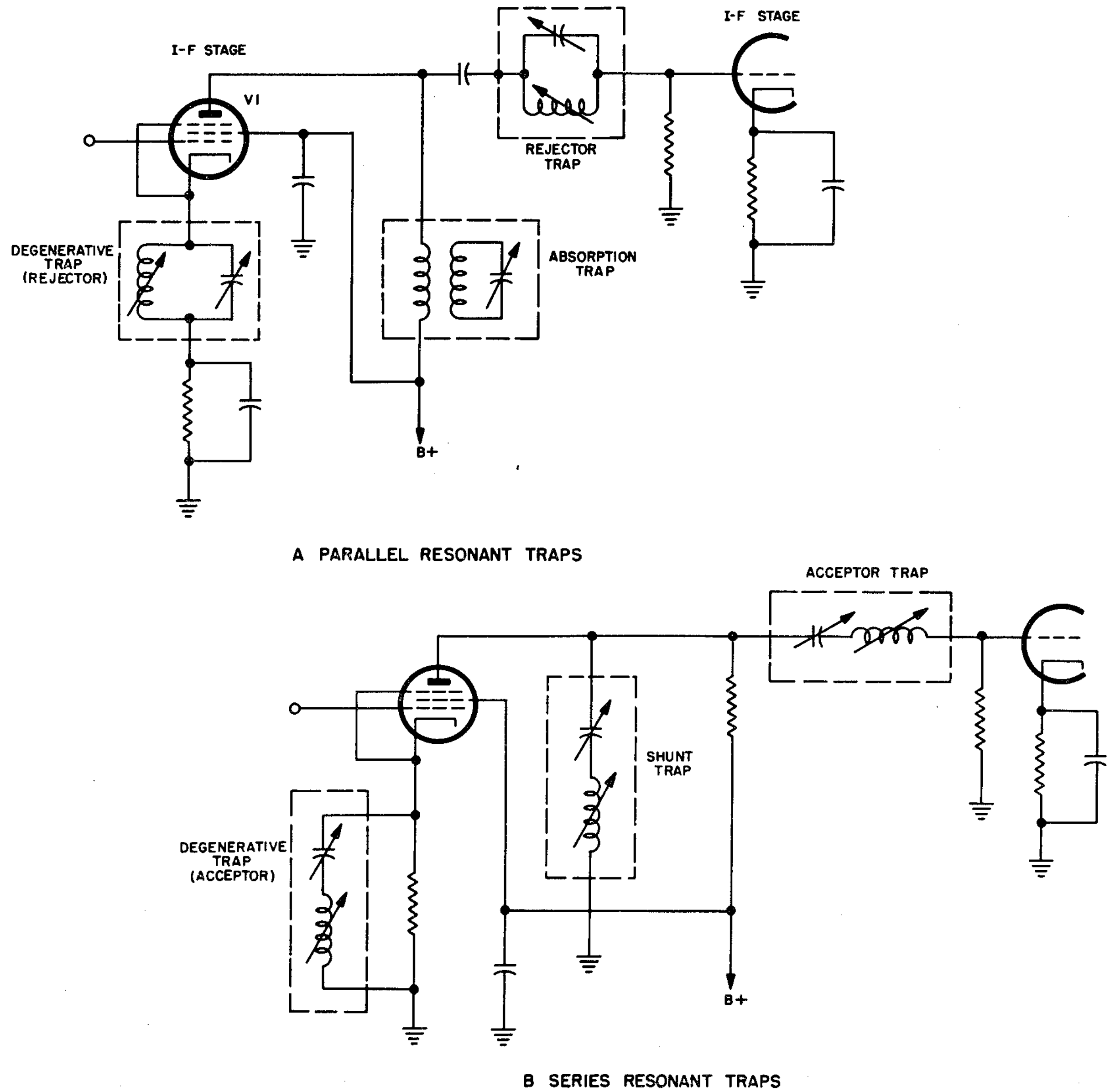


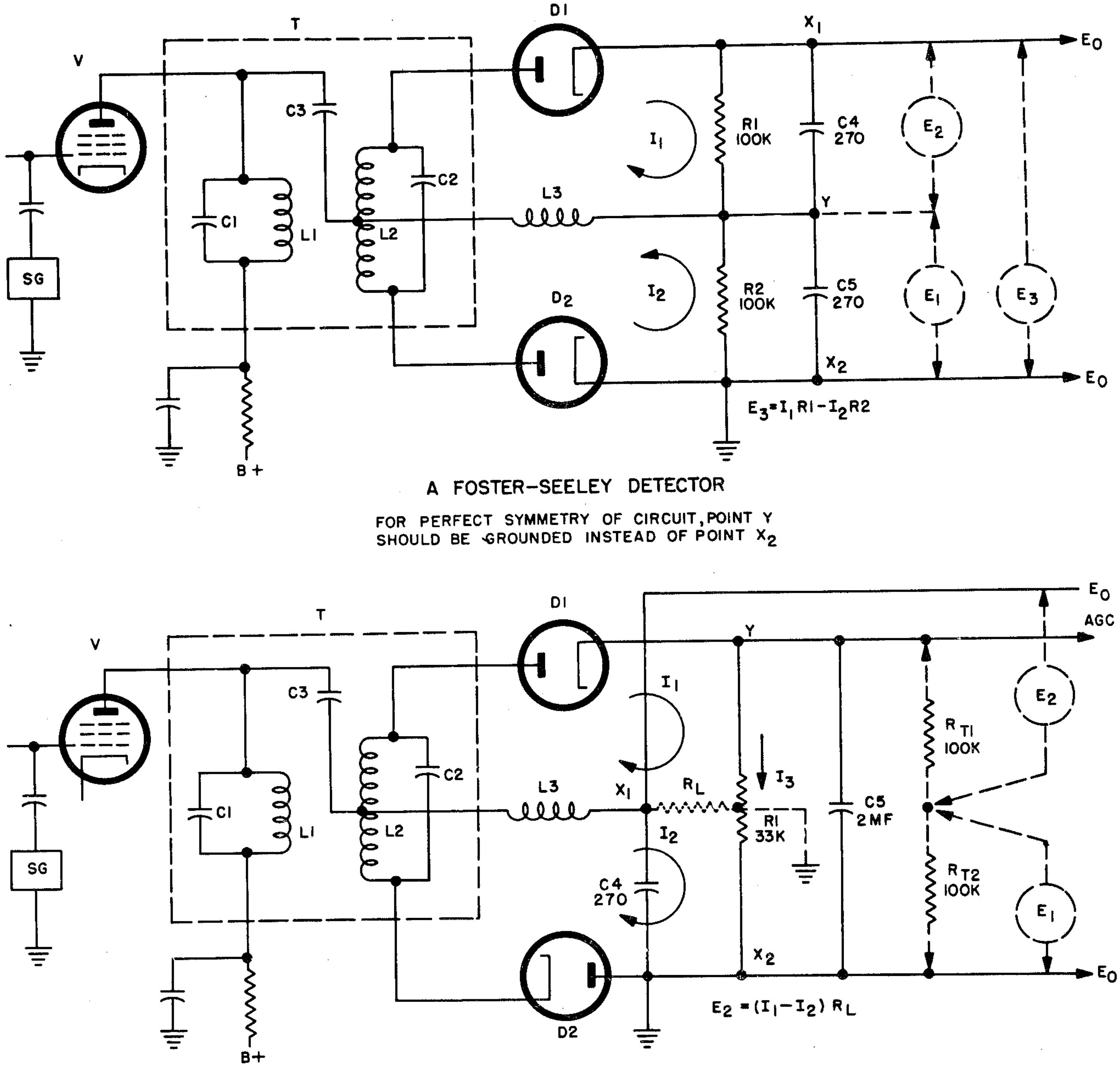
Figure 2-70. ***Composite Circuits, Showing Types of Lumped-Reactor Wave Traps***

discriminator, this balance will occur at the center frequency of the discriminator transformer's pass band. (This, of course, can be true only when the diodes and load resistors are fairly closely matched, the transformer secondary is properly tapped, etc.)

It is the function of the discriminator to produce unequal driving signals at the two diodes as the signal frequency deviates during modulation. With proper design, a d-c output potential proportional to the frequency deviation from the center frequency will then appear at $X_1 - X_2$, with a voltage polarity which depends on whether the deviation is above or below the center frequency. The increasing inequality of the two diode driving-signal voltages with signal deviation from the center frequency is caused by the excursion of the primary and secondary terminal voltages from their ideal 90-degree relative phase. This 90-degree phase angle properly exists between them only at the center of the pass band. (Further theory of discriminator operation is available in standard textbooks and will not be discussed here, since it is not essential to alignment information.)

3. ALIGNMENT OF THE FOSTER-SEELEY (FM) DETECTOR. — A suitable FM signal generator, or swept oscillator, may be used to advantage in aligning the discriminator circuits of any FM detector. However, such equipment is not always available, even in fairly well-equipped laboratories.

It is generally possible to align the usual discriminator system quite satisfactorily with the aid of a standard AM signal generator and an



A FOSTER-SEELEY DETECTOR

FOR PERFECT SYMMETRY OF CIRCUIT, POINT Y SHOULD BE GROUNDED INSTEAD OF POINT X_2

B RATIO DETECTOR

FOR PERFECT SYMMETRY OF CIRCUIT, THE CENTER OF RESISTOR R1 SHOULD BE GROUNDED INSTEAD OF POINT X_2 AND ANOTHER R-F BYPASS CAPACITOR ADDED (=C4) BETWEEN POINTS X_1 AND Y. DOTTED RESISTOR R_L IS EQUIVALENT COMMON PATH IN WHICH OPPOSING RECTIFIED SIGNAL CURRENTS I_1, AND I_2 FLOW

Figure 2-71. Two Types of FM Detectors

electronic d-c voltmeter (high input impedance; not more than 100 $\mu\mu$f capacitance or less than 1 megohm resistance). (It may be necessary to use an isolating resistor (about 1 megohm, non-inductive) between the actual point of connection to the diode load resistor and the tip of the "high" lead to the voltmeter.) The signal generator is used unmodulated to drive the control grid of the amplifier tube (usually designated as a limiter) which precedes the discriminator transformer (see figure 2-71). The alignment screws of the transformer are first adjusted to produce maximum and equal d-c voltages (E_1 and E_2) across the two diode load resistors, with the signal-generator frequency accurately set to the nominal center frequency of the discriminator pass band. The generator output voltage should be adjusted to a level which provides a convenient indication on the d-c voltmeter. This initial adjustment is intended to tune the discriminator transformer

into the pass band in which it is designed to work.

With E_1 and E_2 maximized and equal, the differential d-c voltage E_3 should be zero. E_3 can be read on a lower voltage scale on the meter with greater precision, and the secondary trimming should be touched up so as to produce zero with the meter adjusted to read E_3 on a low scale. When the transformer is properly aligned, substantially equal displacement of signal-voltage readings should be obtained for E_3 with equal displacement of signal-generator frequency on either side of the band center. This condition may be determined by sweeping the signal-generator frequency manually through the detector pass band. Good linearity of voltage change versus frequency should be observed between the two peaks of voltage. With experience, it should be possible to dispense with the E_2 reading and to do the alignment job with the meter grounded on one side, reading only E_1 and E_3.

If the AM signal generator is capable of 400 or 1000 cps amplitude modulation without appreciable frequency modulation and carrier shift, it may be used to advantage in the modulated condition to indicate proper alignment of the discriminator secondary. The generator carrier should be tuned to the center of the discriminator pass band as described above, but with modulation turned on (30 percent is suggested). Then, after trimmer adjustment of the discriminator to produce maximum $E_1 = E_2$, the secondary trimmer should be adjusted to produce minimum 400- or 1000-cps output (E_0), with the generator input voltage set to a value below the threshold of limiting for amplifier V.

There can be individual differences in transformer design (for instance, in coupling coefficient) which may require modifications in the basic alignment procedure described above. The equipment instruction book should always be consulted before attempting specific discriminator realignment.

4. THE RATIO (FM) DETECTOR. — A variation of the Foster-Seeley detector, generally known as the ratio detector (figure 2-71B), is also in widespread general use. The basic difference between these two detectors lies in the employment of rectifier output current opposition in a common load resistance in the ratio type, as compared to rectifier output voltage opposition with two separate load resistors in the Foster-Seeley detector. In both types, the discriminator portion of the circuit is essentially the same.

The utilization of current opposition in a common resistive path allows the two rectifiers to be connected in series aiding across the discriminator transformer's secondary terminals. With a long-time-constant R-C network in series with the diodes (R1C5 in figure 2-71B), the combination can function as a half-wave amplitude limiter which loads the discriminator transformer T. Also R1 controls the effective resistive loading offered by the rectifier diodes to the discriminator transformer.

The differential current $I_1 - I_2$ appears in the common resistive path R_L. However, since R1 controls the effective diode resistance, R_L is relieved of the duty and may be of almost any desired value. It is, in fact, often omitted completely, as in figure 2-71B.

Proper symmetry of the detector characteristic (d-c output voltage versus frequency) will be obtained only when R1 is grounded at its electrical center. In most cases, however, a much more economical design results when the ground is placed at one end of R1. It is then necessary to provide a center tap on R1 for alignment purposes. This can be easily accomplished by external means, if such a facility is not already incorporated in the detector, by shunting the series combination of two equal resistors ($E_{T1} + R_{T2}$) across R1. The junction between these resistors provides the desired reference point. $R_{T1} + R_{T2}$ should be much higher in resistance value than R1 ($R_{T1} + R_{T2}$ = more than $5R_1$).

5. ALIGNMENT OF THE RATIO (FM) DETECTOR. — An AM signal generator and a high-impedance d-c voltmeter may be used for ratio-detector alignment, in much the same way as with the Foster-Seeley detector. The generator should be connected through a capacitor to the control grid of the pre-detector amplifier V. The voltmeter should first be connected either across the diode series resistor R1, or between the $R_{T1} - R_{T2}$ junction and ground, to provide the voltage reading E_1. This will give a direct indication of the signal voltage appearing across the secondary winding of discriminator transformer T. The transformer trimmer screws should be adjusted to maximize E_1, with a suitable level of unmodulated-carrier input applied to V at the nominal center frequency of the discriminator pass band. (Up to this point, the ratio-detector alignment procedure closely resembles the procedure used in an AM receiver for the stages preceding the detector.)

The "low" terminal of the voltmeter should then be connected to the junction of R_{T1} and R_{T2}, and its "high" terminal to point X_1 (figure 2-71B). This will provide for reading differential voltage E_2, which is the useful signal output of the detector. The secondary trimmer of the discriminator transformer should be adjusted to produce $E_1 = 0$, with the signal-generator frequency accurately set to the center frequency of the discriminator pass band. The resulting detector characteristic should be symmetrical between opposite voltage peaks, as determined by rapid sweep of the signal-generator frequency through the discriminator pass band.

6. ALIGNMENT OF SIDE-TUNED FILTER (FM) DETECTORS. — Whether a single-peak filter, or two filters equally displaced on either side of the center frequency are employed, the alignment procedure is quite simple. Each filter is trimmed to produce maximum response from its associated diode (or other) rectifier at the signal peaking frequency specified by the equipment instruction book. In the case of a two-filter system, the trimming may be "touched-up" at the center frequency of the desired pass band so that the composite output voltage of the opposing rectifier load resistors is zero.

(*d*) CIRCUIT ALIGNMENT (GENERAL). — With most types of radio equipment employing either variable (ganged) or fixed synchronized tuning for frequency selection, circuit alignment adjustments are best begun in the circuits farthest removed from the antenna. Adjustment then proceeds toward the antenna, with the antenna circuit proper usually being the last one adjusted.

This general "rule" holds typically for the superheterodyne receiving system which has been discussed previously as an example of tuned-circuit alignment. Here the i-f amplifier (the final i-f amplifier if more than one conversion is employed) is aligned first. The i-f signal is usually fed into the input electrode of the preceding mixer tube through a coupling capacitor (of suitably large value) from the signal generator. If the pre-mixer circuits are variable-tuned, as in a single-conversion heterodyne receiver, the tuning control should be adjusted to a position near the lowest frequency in the lowest frequency band of the receiver. This adjustment is desirable as a means of insuring that the generator signal input is not effectively short-circuited at the intermediate frequency by the signal input circuit driving the mixer. In general, the more nearly the signal circuit resonant frequency approaches the intermediate frequency, the higher will be the signal circuit impedance at the intermediate frequency.

The signal input level at the final detector or demodulator is an effective measure of circuit alignment. One of the best indicators of relative input level at that point is by the change of detector rectified output voltage. This voltage can be measured by the use of a high-impedance electronic d-c voltmeter, connected so as to minimize disturbance to the detector circuit. Alternatively, it may be more feasible to observe the modulation output voltage at the output terminals of the receiver.

1. AM RECEIVERS. — Prior to alignment of an AM receiver, the AGC (automatic gain control) should be turned off, and the gain should be adjusted, by means of the manual r-f gain control, to produce a medium value of input reactance in those tubes which are being controlled. For Navy communications receivers, this is the gain level which would give the standard 6 milliwatts of audio output with about 100 to 1000 microvolts of signal input at the antenna. This alignment condition is desirable to reduce the detuning effect of receiver gain variations as reflected in changes of over-all selectivity. It insures that the circuits will be resonated under average load conditions, at approximately the middle working value of tube input reactance, and with freedom from serious regeneration.

With most communications receivers, this condition also reduces receiver noise to a degree which makes it unnecessary to quiet the receiver by removing a tube in the amplifier stage preceding the point of alignment-signal injection. The preselector main tuning control should be adjusted to a low frequency, as already mentioned, retuning slightly, if necessary, to insure that no unwanted signal is present. For preselector alignment, the antenna should be disconnected from the receiver.

AM receiving equipment which operates with automatic gain control as a permanent condition, with no built-in provision for the alternative manual control of r-f and i-f gain, may present a problem, especially if considerable regeneration is normally present at full gain. It may not be feasible to disable the agc and to add a temporary battery-biased manual gain control potentiometer in its place. In such cases, it will be necessary to align each section of the receiver with suitable signal-input levels at each point of injection to produce final detector operation below the threshold of a-g-c action. A tube should be removed in a stage preceding the point of alignment-signal injection, to preclude the presence of unwanted signals and noise.

It is preferable not to disable the heterodyne oscillator(s) when aligning a receiver, except for the beat-frequency oscillator (bfo) which is used to provide tone output from the final detector in code (cw) reception. The heterodyne oscillator injection voltage ordinarily is a major factor controlling the mixer tube operating bias and impedance, with consequent influence on gain and both mixer input and output circuit resonance. The beat-frequency-oscillator injection voltage in a properly designed c-w receiver usually produces a large fixed bias at the final detector which will mask its rectified voltage changes. This masking is very objectionable when the rectifier signal voltage is employed as an output indication for alignment.

In some cases, suitable adjustment of heterodyne oscillator tuning may not be feasible as a means for preventing undesired beats or spurious signals that may result from the interaction of the alignment signal and the heterodyne injection

voltage. The oscillator must then be disabled, preferably by removing either the oscillator tube or the final multiplier tube (if the heterodyne system employs frequency multipliers). Stopping an oscillator by short-circuiting its grid to ground, or by shorting its tank circuit, may cause serious damage to the oscillator tube and other components.

Before starting the actual alignment, all those auxiliary functions provided in the receiver which may interfere with proper output indication or circuit resonance should be disabled. This includes agc (except as previously discussed), silencer or squelch action, noise and output limiters, etc.

2. I-F AMPLIFIER ALIGNMENT. — With a few exceptions, such as some trap circuits, i-f resonant circuits are aligned by adjusting their trimmers to produce maximum signal voltage. The i-f trimmers of the typical AM receiver are thus adjusted to produce maximum final-detector signal input voltage, using the input-signal frequency or frequencies prescribed in the instruction book for the equipment. In many cases, this will be the nominal band-center frequency of the particular i-f system. In other instances, usually involving relatively wide i-f pass bands, "peaking" of some or all trimmers for maximum response at one or more frequencies off the band center will be specified.

In general, the last i-f transformer preceding the detector should be aligned first, unless some other order is required in the equipment instruction book. The input from the signal generator should be adjusted to produce a signal output level which is well above the noise level at the output indicator, but which is also well below saturation or overdrive level for the vacuum tubes of the system. The signal input should be progressively reduced as needed, as more circuits are brought into proper alignment, with the progression of circuit adjustment moving toward the mixer stage. After the first round of alignment adjustments of the i-f system is completed, the i-f alignment should be checked (and possibly rechecked) over-all.

A similar procedure should be used for the alignment of the preceding i-f amplifier(s) in receivers employing more than one frequency conversion. The i-f signal input should, in each case, be injected at the input electrode of the mixer preceding that particular i-f amplifier. This insures inclusion of the i-f transformer which is located in the output circuit of the mixer. The associated conversion oscillator should be disabled if really necessary, as previously discussed.

3. R-F TUNER (PRESELECTOR) ALIGNMENT.—Navy superheterodyne receivers generally employ at least one stage of r-f amplification in their preselectors. As a result, there are usually not less than three controllable resonant circuits in such a unit, ganged together for one-control tuning and tracked in frequency to maintain the desired resonance relationships over each tuning band. The primary windings (where used) on the r-f transformers are also resonated in definite frequency regions; these regions, however, are fixed by coil design and circuit structural features, and the primaries seldom have provision for modification of resonance by trimmers.

The antenna and r-f interstage variable-tuned circuits are designed to track together closely in frequency, and generally employ identical variable-capacitor sections for tuning. However, the tank inductors for these circuits do not all have the same value of inductance, because of differences in the mode of operation. The antenna coil and capacitor are required to resonate with the complex r-f impedance of an antenna system, more or less loosely coupled, to produce an optimum signal at the control grid of the first tube. This makes the antenna primary and secondary inductances differ from those used interstage, where the driving impedance is provided by the plate circuit of a vacuum tube.

The oscillator tank must resonate higher (or lower) in frequency than the signal, by an amount equal to the intermediate frequency. The value of oscillator tank inductance must therefore differ from the values for the antenna and interstage circuits. In addition, satisfactory oscillator tracking with variable-capacitor tuning can be obtained over a considerable tuning range only by supplying a tuning capacitance which differs markedly from the capacitance needed by the other r-f circuits. In multiband receivers, this cannot be done economically with "cut" or differentially shaped capacitor plates. Instead, an adjustable padder capacitor in series with the variable tuning capacitor is used in each band to provide an approximately corrected effective tuning capacitance. This, however, normally results in tracking which is accurate at only three points in frequency in each band, two of these points being trimmed points.

4. DETAILED PRESELECTOR ALIGNMENT PROCEDURE.—In addition to a suitable signal generator, the dummy antenna specified by the receiver instruction book should be used, to simulate an ideal antenna system for the receiver. A typical alignment procedure is described below.

The signal generator (modulated or unmodulated, as required) should first be accurately adjusted to the upper alignment frequency specified for the particular receiver tuning band, using an external frequency standard if necessary. If an antenna trimmer control is provided on the front panel of the receiver, it should be set to the middle of its range. The receiver is then carefully tuned to that signal frequency, and the generator

output is adjusted to produce the desired maximum (or other specified optimum) deflection on the receiver output indicator. The tuning-dial frequency indication should coincide closely with the signal frequency being supplied. If it does not, the tuning dial should be reset to indicate the proper frequency. The high-frequency (shunt capacitance) trimmer of the oscillator tank circuit should then be adjusted to produce optimum output from the test signal. Following these adjustments, the interstage and antenna circuit shunt-capacitance trimmers should be adjusted for optimum output, with the test signal input level reset as needed to avoid receiver saturation effects.

Oscillator shunt trimmers occasionally have unusually wide range of adjustment. For this reason and for other reasons, it is possible to misalign the circuits so as to place the heterodyne oscillator on the wrong side of the signal frequency. In many instances, this mistake will be revealed in inability to obtain anything resembling good circuit tracking over the tuning band. Sometimes, however, the mistake will not be so clearly apparent. Therefore, it is always wise to ascertain that the oscillator is being trimmed on the proper side of the desired signal frequency. Determination of the proper relationship from the equipment instruction book, and careful observation of shunt trimmer positioning (whether its capacitance is increasing or decreasing relative to the two positions of heterodyne response which it produces) will help to prevent error.

Next, it is necessary to check oscillator alignment at some specified frequency near the low-frequency end of the tuning band. In many military receivers, iron-core or eddy-current trimmers are provided in the r-f coils to permit tank inductance adjustments for optimum low-frequency tracking of all the r-f circuits. The inductance adjustments should be made on all coils except the oscillator coil before the oscillator series padder is checked. Then the series padder should be trimmed to produce optimum output while the receiver tuning control is "rocked" back and forth through the region of best signal response. When this process is completed, the shunt trimmer adjustments should be touched up for optimum response and correct tuning-dial reading (calibration) at the high-frequency alignment point in the band. The low-end padder adjustments should then be touched up for optimum response, and the tuning-dial reading should be checked against the test-signal frequency.

If oscillator tracking relative to the other r-f circuits is poor over the band, as indicated by abnormal variations of gain (and/or output noise) as the tuning control is operated throughout its range, it may be necessary to adjust the oscillator tank inductance trimmer. The correction needed to produce better tracking may be determined by trial readjustment of the oscillator shunt-capacitance trimmer. If the tracking (as checked by tuning from the high-frequency to the low-frequency alignment points) can be improved by increasing the shunt trimmer capacitance, the oscillator tank inductance is low. If the shunt trimmer capacitance must be decreased to obtain improvement, the tank inductance is high. Correction adjustment of oscillator tank inductance will necessitate some changes in oscillator series-padder and shunt trimmer adjustments, and the entire preselector alignment procedure must be repeated.

If the tuning dial is then still in error over part of the band, it may be possible to correct the calibration to some degree by further slight readjustments to the oscillator and other trimmers. This realignment should be undertaken only after careful study of the tracking discrepancies and calibration errors over the entire band, and with a full understanding of the superheterodyne tracking problem if adequate instruction book directions are not available. In general, it is inadvisable to sacrifice receiver gain and selectivity for the minor convenience of accurate tuning-dial calibration.

Receivers that incorporate i-f traps in their preselector circuits should be checked by the use of a preselector input signal at the intermediate frequency, obtained from the signal generator. The trimmers for such traps are usually adjusted for minimum output at the center frequency of the first i-f amplifier, and may require large input signal amplitude at that frequency.

5. FM OR PM RECEIVER ALIGNMENT.—The FM or PM receiver differs from the AM receiver only in two basic elements: (1) instead of an amplitude-sensitive detector, a frequency-sensitive final detector or demodulator is provided, and (2) the i-f amplifiers preceding the detector are designed to facilitate rather than to avoid amplitude limiting. The alignment procedures for FM (or PM) detectors have been discussed in a previous part of this section of the manual. The resonant circuits of the FM detector should be in proper alignment before alignment of any other portion of the receiver is begun. The rectified d-c output of one diode of the detector (e.g., E_1 in figure 2-71) may be used as the output indicator for aligning the i-f stages.

The general procedure for pre-detector circuit alignment is essentially the same as for AM receivers. It should be noted, however, that the pass band of the discriminator transformer is often wider than that of the preceding i-f transformers. This is usually apparent as a greater frequency spacing between the two peaks of d-c differential voltage output from the FM detector rectifiers (E_3 in figure 2-71A and E_2 in figure 2-71B). This

greater bandwidth is a design precaution usually intended to insure low output distortion. As a rule, the center of the discriminator pass band should be located at the center frequency of the pass band of the preceding i-f amplifier. If this is not done, serious distortion of the output signal may be encountered, resulting from differential attenuation of the upper and lower sidebands of the signal in the discriminator.

6. ALIGNMENT OF OTHER TYPES OF EQUIPMENT. — Transmitting equipment usually has built-in provisions for adjustment and indication of proper alignment in each stage. The order of alignment usually progresses from the oscillator to the antenna circuit.

The oscillator and frequency multipliers used in various crystal-controlled Navy VHF-UHF receivers are likewise aligned progressively from the oscillator to the mixer stage. In some designs, the a-g-c system of the receiver is used as a means of indicating the output of the oscillator and individual multiplier stages, in turn, during alignment.

Auxiliary receiving adapter devices, such as panoramic indicators and FSK converters, generally require the same sort of alignment procedures as superheterodyne i-f systems. Some intercept receivers use sweeping oscillators, as do the panoramic devices. These are essentially modulated heterodyne oscillators of different types. The FSK converters employ limiting amplifiers, together with some form of FM detector. In all these devices, some variation of the basic alignment procedure will apply. Information as to the actual steps, however, is best obtained from each particular equipment instruction book, and no attempt to provide a detailed general review (such as presented for the superheterodyne receiver) will be made in this manual.

7. WAVE TRAPS. — The term "wave trap" usually refers to a resonant element that is used as an auxiliary device for providing additional frequency selectivity in a radio circuit at a particular frequency. It may take a distributed form (resonant stub or cavity), or may consist of a lumped reactor combination (inductor and capacitor) as in figure 2-70. A trap normally provides a means for rejecting (or accepting) signals over only a relatively narrow band of signal frequencies, of a width which depends in part on the effective Q of the trap circuit.

The trapping desired may result from the "shorting" effect of a series-resonant circuit shunted across the signal path; from the selective opposition to the flow of current afforded by a high value of resonant impedance in series with the path; from selective degeneration in an amplifier, produced by using resonant circuits to provide frequency-dependent feedback; etc.

Some of the more common lumped-reactor wave-trap applications are shown in figure 2-70. In addition to those illustrated, many other forms may be found in radio equipment. In some applications, a wave trap is used to suppress response at a frequency not desired in one channel, and the resulting trap resonance at that frequency is used as a means for supplying signal to a second channel. Resistance-capacitance (RC), resistance-inductance (RL), and inductance-capacitance (LC) networks affording high-pass and low-pass characteristics are also employed to provide band-elimination or band-pass effects for wave-trapping purposes.

8. WAVE-TRAP ALIGNMENT. — The operating frequencies and apparent effects of wave traps differ from one type of equipment to another. In general, it can be expected that the traps will be left until the last steps in a prescribed alignment procedure, because of their auxiliary or corrective nature. Adjustment of wave-trap trimmers must usually be accomplished at very specific frequencies and under particular conditions which should be rigidly observed. If adequate instructions for wave-trap alignment are lacking in an equipment instruction book, immediate steps should be taken to obtain further instructions. An incorrectly adjusted trap circuit may produce serious shortcomings in equipment operation which are not apparent to the operator under ordinary conditions.

The signal generator and output indicator commonly employed in the alignment of receiver selective circuits will usually serve for wave-trap alignment in receiving equipment. Other forms of radio equipment employing traps may require special instrumentation such as measuring receivers and oscilloscopes.

2-12. ELECTRON TUBE TESTING.

Electron tubes are generally considered as the most essential components of electronic equipments. Some of the more important factors which affect the life expectancy of an electron tube are: (1) the circuit function for which the tube is used, (2) deterioration of the cathode (emitter) coating, (3) decrease in emission of impregnated emitters in filament-type tubes with age, (4) defective seals which permit air to leak into the envelope and oxidize the emitting surface, and (5) internal short circuits and open circuits caused by vibration or excessive voltage. If the average receiving tube is not overdriven, nor operated continuously at maximum rating, it can be expected to have a life of at least 2,000 hours before the filament opens. Because of the attendant expansion (and contraction) of the tube elements during the process of heating (and cooling), the electrodes may lean or sag, causing excessive noise or microphonics to develop. Other electron-

tube defects are cathode-to-heater leakage and nonuniform electron emission of the cathode. Tube defects, of which only the most common are listed above, contribute to about 50 percent of all equipment failures. For this reason it is good practice for the technician, when he is trouble-shooting equipment, to eliminate immediately any tube known to be faulty; avoiding, however, blind replacement of good tubes by fresh spares. Visible evidence of a tube defect is present when the filament is open (glass-envelope tubes), when the plate current is excessive, when the tube becomes soft (gassy), or when arcing occurs between electrodes. Metal-encased tubes can be felt to determine whether the heater is operating. A tube may be tapped sharply while operating in a particular circuit to provide an aural indication of loose elements or microphonics.

a. BASIC ANALYSIS OF TUBE TESTING.—In the following discussion three basic types of tube tests will be covered: the substitution test, the emission test, and the transconductance test. Additional tests which are usually incorporated in field-type tube testers will also be discussed. These tests are: the gas test, the short-circuit and noise test, the cathode leakage test, and the filament activity test.

(1) THE SUBSTITUTION TEST.—Substitution of a tube known to be in good condition is a simple method of determining the quality of a questionable tube. However, in high-frequency circuits tube substitution should be carried out carefully one at a time, so that the effect of differences in interelectrode capacitances of the substituted tubes on tuned (aligned) circuits can be noted. The substitution method of testing cannot be used to advantage to locate more than one faulty tube in a single circuit. If both an r-f amplifier tube and an i-f amplifier tube are defective in a receiver, replacing either one does not correct the trouble. If all the tubes are replaced, there is no way of knowing which tubes were defective. Under these or similar conditions the use of a test equipment designed for testing the quality of a tube saves valuable time.

(2) THE EMISSION TEST.—An important indication of the condition of a tube is obtained by a comparative check of the cathode (or filament) emission, because in most cases a pronounced lower-than-normal emission, or a complete loss of emission, indicates that the tube has reached the end of its useful life. Both multigrid and diode tubes are tested for cathode emission.

(*a*) TESTING MULTIGRID TUBES. — For a test of the emission of a multigrid tube, the tube is connected as a half-wave rectifier as shown in figure 2-72. The plate and all the grids of the tube are connected together, a current meter

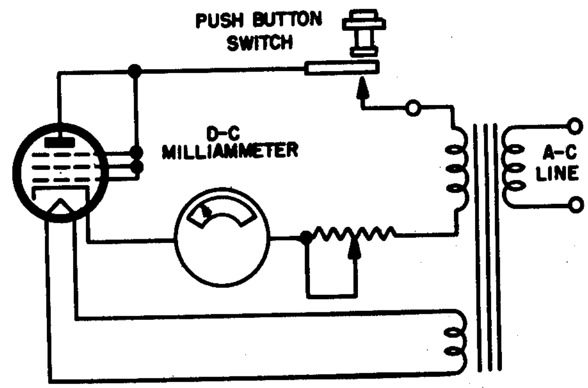


Figure 2-72. Basic Circuit Used for Emission Test

and variable resistor are placed in series with the tube, and the entire circuit is connected across a transformer secondary. Because of their common connection, the plate and all of the grids are at the same potential with respect to the cathode. As a result, the tube functions as a diode rectifier, conducting current only on the alternate half-cycles when the plate and grids are positive with respect to the cathode. The amount of current that flows indicates the condition of the cathode emitting surface. On tube-testing test equipments the meter scale is usually calibrated by dividing the total pointer arc into three areas, which are labeled GOOD, WEAK, (or FAIR), and BAD.

(*b*) TESTING DIODE TUBES. — The emission test for diode (and rectifier) tubes and the diode part of multisection tubes is similar to the emission test used for multigrid tubes. The tube filament or heater is operated at the rated value, and an a-c voltage is applied to the test circuit consisting of the diode, a d-c milliammeter, and a variable resistor. A tapped secondary is utilized in some circuits to control the voltage applied to the tube under test. The variable resistor limits the tube current to a safe value. The amount of current flowing through the resistance and the meter depends on the electron emission within the tube, and therefore indicates the emission quality of the tube.

(3) THE TRANSCONDUCTANCE TEST. The term transconductance (also called mutual conductance) expresses the effect of grid voltage upon the plate current of a tube. By measuring the transconductance of a tube it is possible to evaluate the condition of the tube much more accurately than by measuring its cathode emission, because this test more closely approximates actual circuit conditions. Transconductance is expressed mathematically as the ratio of a change in plate current to a change (small) in control-grid voltage with all other electrode voltages held constant. Transconductance is measured in units of conductance called micromhos. The equation for

transconductance is:

$$G_m = \frac{\Delta I_p}{\Delta E_g}$$

where G_m is the tranconductance in micromhos, ΔI_p is the change in plate current in microamperes, and ΔE_g is the change in control-grid voltage. When the control-grid voltage changes 1 volt (positive or negative), the current change in microamperes is equal to the transconductance in micromhos. In other words, if an amplifier tube has a transconductance of 2000 micromhos, a 1-volt change in the control-grid voltage will cause a plate-current change of 2000 microamperes. The transconductance of a tube may be measured by two methods: one method is the static (d-c) method and the other is the dynamic (a-c) method.

(*a*) THE STATIC METHOD. — In the static method (also called the "grid shift" method) of measuring transconductance, the d-c bias voltage on the control-grid of the tube under test is changed, and the resultant change in the steady plate current is measured with a current meter. The test circuit is shown in part (A) of figure 2-73. With switch S set to position 1, a negative bias voltage is applied to the control grid of the tube and causes a certain value of plate current to flow. When switch S is thrown to position 2, the control-grid voltage becomes less negative, and the plate current increases to a new value. If the control-grid voltage is varied by 1 volt, the transconductance is the difference (in microamperes) between the initial plate-current reading and the new value of plate current. When such a circuit is used to test various types of tubes, the voltages applied to the electrodes must be made adjustable, so that the correct operating conditions for each tube type may be attained.

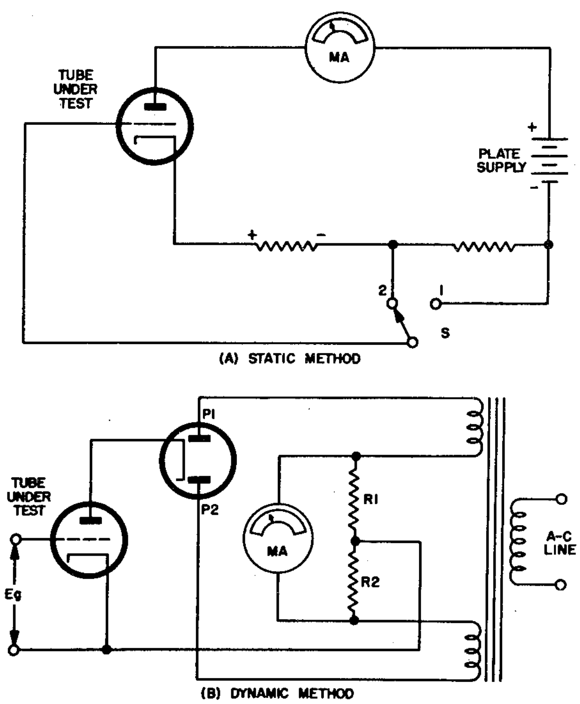


Figure 2-73. ***Basic Circuits Used for Transconductance Test***

(*b*) THE DYNAMIC METHOD. — The dynamic method of determining transconductance makes use of a circuit which applies an a-c signal to the control grid of the tube under test, in addition to a fixed (operating) control-grid bias. The basic circuit is shown in part (B) of figure 2-73. The tube under test serves as the load for the rectifier circuit. The d-c milliammeter is connected across a center-tapped resistor, the upper and lower parts of which are designated as R1 and R2. The meter and resistor combination is placed in series with two secondary windings of the a-c line-voltage transformer. With a fixed value of bias voltage (E_g) applied to the control grid of the tube under test, the circuit operates as a simple full-wave rectifier. On the half-cycle of the a-c voltage when plate P1 of the double diode is positive, there is a current flow through R1, and the force exerted on the meter pointer attempts to deflect it in one direction. When the a-c voltage reverses and plate P2 is positive, the current flows through R2, and the force exerted on the meter pointer is equal and opposite to the previous force. Since these alternations occur at a rather rapid rate (60-cycle line voltage), the resultant force exerted on the meter pointer is zero; consequently, it remains stationary in the zero position.

While the fixed d-c bias voltage is still maintained, an a-c voltage from a secondary of the line-voltage transformer is applied to the control grid of the tube under test. If this applied voltage swings positive at the same time that P1 is positive, the plate current of the triode increases (plate-cathode resistance decreases). Since P1 is positive and conducting, current flows through R1, increasing the deflecting force on the meter pointer in one direction. When the a-c voltage applied to the control grid swings negative, the control grid becomes more negative, decreasing the tube current (plate-cathode resistance increases). With P2 now positive and conducting, the current through R2 decreases, and as a result the deflecting force on the meter pointer on this half of the a-c cycle is not sufficient to cancel the force exerted during the previous half-cycle. Hence, the meter deflection is unidirectional, and is proportional to the difference of the currents in R1 and R2 resulting from the application of the a-c voltage to the grid of the triode. Therefore, the meter reading indicates the change in plate current produced by a change in grid voltage under dynamic conditions. For tube-testing purposes, this increase in plate current is used to indicate the transconductance of a tube under

test. Any pronounced deviation from the rated, or normal, transconductance for a specific tube indicates either a defective or an ineffective tube. The meter can be calibrated in terms of good, fair, and bad, or in micromhos.

(4) ADDITIONAL TESTS. — The emission tube tester and the transconductance tube tester, which are the two common types of tube-testing equipments employed in the field, may also incorporate circuits for making the following tests: gas test, short circuit and noise test, cathode leakage test, and filament activity test. These tests will be explained in the following paragraphs.

(*a*) THE SHORT CIRCUIT AND NOISE TEST.—It is very important that the technician apply the test for short-circuited elements to a tube of doubtful quality before any other tests are made. This procedure protects the meter (or any other indicator) from damage. Also it follows logically that, if a tube under test has elements which are short-circuited, there is no further need to apply additional tests to that tube. Short-circuit tests are usually sensitive enough to indicate leakage resistance less than about ¼ megohm. The proper heater voltage is applied so that any tube elements which might short as a result of the heating process will be detected. The short-circuit test is similar to the test used to detect noisy (microphonic) or loose elements. Since the only difference between the two tests is in the sensitivity of the device used as an indicator, the noise test will be discussed as part of the short-circuit test.

Figure 2-74 shows a basic circuit used for detecting shorted elements within a tube. With the switch set to position 2 as shown, the plate of the tube under test is connected to the leg of the transformer secondary containing the neon lamp. All the other elements are connected through switches to the other leg of the secondary. If the plate element of the tube is touching any other element within the tube, the a-c circuit of the secondary is completed and as a result both plates of the neon lamp glow. If no short exists, only one plate of the neon lamp will glow. Each of the other elements is tested by means of the switching arrangement shown. Resistor R2 limits the current through the neon lamp to a safe value. Resistor R1 by-passes any small alternating currents in the circuit which might be caused by stray capacitance and thus prevents the neon lamp from indicating erroneously. Tapping the tube lightly is recommended to detect loose elements which might touch when the tube is vibrated.

The noise test is in effect nothing more than a very sensitive short-circuit test. In figure 2-74 two leads are taken from either side of the neon lamp and brought to external receptacles which are labeled noise test. A high-gain amplifier (with speaker) is connected to these receptacles. Perhaps the handiest amplifier for this test is an ordinary radio receiver. The antenna and ground terminals of the receiver are connected to the noise test jacks, and a normal short-circuit test is made while tapping the tube. If tube elements are loose—perhaps not loose enough to indicate on the neon lamp—loud crashes of noise (or static) will be heard from the receiver over and above the normal amount of noise that is present. The noise test may also be made without the use of the high-gain amplifier merely by inserting the leads from a pair of headphones into the noise test receptacles. The latter check, of course, is not as sensitive as the test made with the amplifier, but is generally more sensitive than the short-circuit test made with the neon lamp as an indicator.

(*b*) THE GAS TEST. — In all electron tubes except some types of rectifier tubes the presence of any appreciable amount of gas is extremely undesirable. When gas is present, the electrons emitted by the cathode collide with the molecules of gas. As a result of these collisions, electrons (secondarily emitted) are dislodged from the gas molecules, and positive gas ions are formed. These ions are attracted by (and cluster around) the control grid of the tube, because it is negative (bias) and absorbs electrons from the grid circuit in order to revert to the more stable gas molecules (not ionized). If the amount of

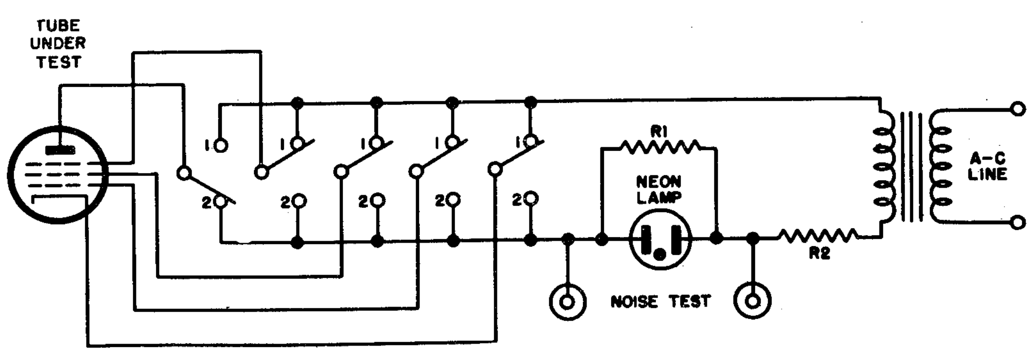


Figure 2-74. Basic Circuit Used for Short-Circuit and Noise Tests

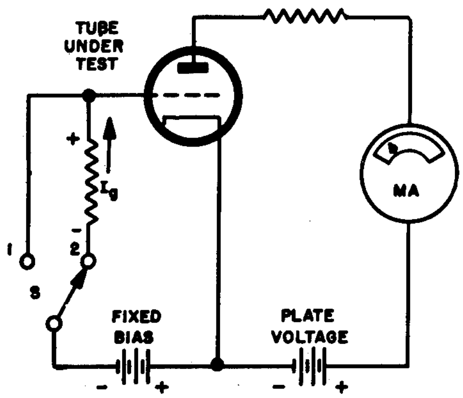


Figure 2-75. Basic Circuit Used for Gas Test

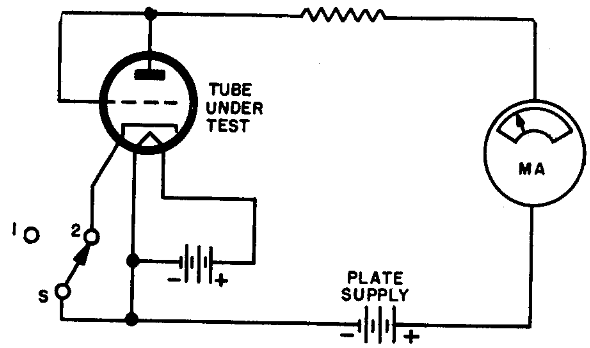


Figure 2-76. Basic Circuit Used for Cathode Leakage Test

gas in the tube is appreciable, the collisions between the numerous gas molecules and the cathode-emitted electrons release many secondarily emitted electrons, and the resulting flow of grid current is high. The basic circuit used for the gas test is shown in figure 2-75. With switch S set to position 1, a certain value of plate current is measured by the d-c milliammeter. If there is no gas (or a negligible amount) present in the tube, throwing switch S to position 2 does not change the plate-current reading. If gas is present, current flows through the grid resistor (large value), causing a voltage drop to develop with the polarity as shown. The net effect is to reduce the negative bias voltage on the grid of the tube resulting in an increase of plate current. Small plate-current increases are normal; large increases indicate excessive gas.

(*c*) THE CATHODE LEAKAGE TEST.—The cathode element of an electron tube is essential because it supplies the electrons necessary for tube operation. Electrons are released from the cathode by means of some form of energy—generally heat—which is applied to it. An indirectly heated cathode consists of a heater wire (usually a tungsten alloy) enclosed in, but insulated from, a metal sleeve (nickel). This sleeve is coated with an electron emitting material (usually strontium or barium compounds) on its outer surface, and is heated by radiation and conduction from the heater. Useful emission does not take place from the heater wire.

When a tube which uses an indirectly heated cathode develops noise, it is almost a certain indication that a leakage path is present between the cathode sleeve and the heater wire. This assumption is justified because in the design of a tube the heater must be placed as close as possible to the cathode so that maximum tube efficiency is attained. Continual heating and cooling of the tube structure may cause small amounts of the insulation between the cathode and heater to become brittle or deteriorate, leaving a high resistance leakage path between these elements. Under extreme conditions the insulation may shift enough to allow actual contact of the elements. Since the heater and cathode are seldom at the same potential, any form of leakage causes noise to develop in the tube. The cathode normally is maintained at a higher positive potential, because cathode bias is the most common type of bias utilized. The heater circuit is usually grounded to chassis, either on one side of the filament supply or by a center-tap arrangement. Therefore, if a resistance path is present, a leakage current may flow from the heater to the cathode. Thus, in effect the cathode functions in the same manner as the plate of a tube; that is, it receives electrons. Assuming the existence of a high-resistance short, the current flow from the heater to the cathode will vary with any vibration of the tube because vibration varies the amount of resistance. If the cathode and heater are completely shorted (zero ohms), it is impossible for the tube to develop any cathode bias.

A cathode leakage test is sometimes made while a tube is being tested for short-circuited elements or noise. However, some tube-testing instruments incorporate the cathode leakage test as an additional test which is not part of the short-circuit test. Figure 2-76 shows a basic circuit which is used to detect leakage between the heater and cathode elements of a tube. With switch S set to position 2, a certain value of plate current flows. When switch S is thrown to position 1, the cathode becomes a floating element; if no leakage path is present, the plate current should fall to zero. If the elements are completely shorted, the plate current reading remains the same as the initial reading (switch S in position 2); if they are only partially shorted, a plate current less than normal but greater than zero is indicated.

(*d*) THE FILAMENT ACTIVITY TEST.—The filament activity test is used to determine the approximate remaining life of an electron tube insofar as the longevity of the cathode

emitter is concerned. The test is based on the principle that the cathode in almost all electron tubes is so constructed that a decrease of 10 percent of the rated heater voltage causes no appreciable decrease in emission.

On a tube-testing equipment incorporating this test there is a two-position switch (FILAMENT ACTIVITY TEST) which has one position marked NORMAL and the other marked TEST. The switch remains in the NORMAL position for all tests other than the filament activity test. When the switch is set to the TEST position, the filament (or heater) voltage which is applied to the tube under test is reduced by 10 percent.

The filament activity test is performed as follows: After the quality test is made, the TUBE TEST button is held depressed, and the filament activity test switch is set to TEST position. If the indicator shows a decreased reading after a reasonable time is allowed for the cathode to cool, the useful life of the tube is nearing its end.

b. TUBE-TESTING EQUIPMENTS.—A number of different types of equipments have been developed for testing the condition of electron tubes. Bridge-type instruments are used in laboratory work for the measurement of three important parameters of grid-controlled electron tubes: namely, amplification factor (u), plate resistance (r_p), and transconductance (G_m). Diode and rectifier characteristics are checked by measuring the plate current resulting from the application of a specified value of plate voltage. These bridge measurements, as well as the calculations which are a necessary part of the complete laboratory tests, are tedious and time-consuming. To be of practical use to the technician in the field, a tube-testing equipment must provide a simple and quick appraisal of the quality of a tube. While using the same basic principles of laboratory checks, tube tests made by field-type tube testers generally employ simplified methods, so that, even though the test results are limited in accuracy, they serve in a practical manner to evaluate the condition of a tube. Tube-testing equipments, however, have certain limitations in that, although they compare tubes to a predetermined standard, they do not reveal how a tube may operate in a circuit under a specified set of conditions. The final, and most accurate, indication of the condition of a tube is its ability to function in a circuit designed for its use. It is seen then that field-type tube testers, although limited because of their relative inaccuracy, are still considered important as an aid to fast trouble shooting since they provide quick appraisals of the condition of electron tubes.

(1) FIELD-TYPE TUBE TESTERS. — There are two different types of tube-testing equipments in common use in the field at the present time. These equipments, which are distinguished by the tube characteristic tested, are known as the emission type tester and the transconductance type tester.

(*a*) THE EMISSION TYPE TESTER.—The emission tester measures the condition of the cathode emitting surface. The end of the useful life of a tube is usually preceded by a reduction in electron emissivity, that is, the cathode becomes unable to supply the number of electrons necessary for proper tube operation. Also, if the tube has an open element, the defect prevents proper emission, and the tester indicates it as a reject.

The emission type tester has certain limitations and disadvantages. Since the manufacturer of a tube does not state a definite 100 percent emission point which could be used for reference, the emission test is not conclusive. High emission does not necessarily indicate a good tube, because this condition might be present in a tube with a faulty grid structure or one which has a highly emissive spot on its cathode. Very high emission has also been observed just before a tube fails completely; hence, fairly low emission does not necessarily indicate in all cases that a tube is near its end-of-life point. A further disadvantage of the emission test is that gas is liberated within the tube when a-c test voltages are applied unless the test is made quickly. Also, because the tube is not operated with its recommended d-c electrode voltages in this test, it is not tested under actual operating conditions. It is also possible for a tube to show normal emission and still not operate properly. The reason for this is that the efficiency of a tube depends on the ability of the grid voltage to control the plate current. The emission type tester tests only the plate current developed, and not the ability of the grid to control the plate current. The transconductance type tester checks the latter characteristic.

(*b*) THE TRANSCONDUCTANCE TYPE TESTER.—The transconductance type of tester provides a more accurate evaluation of the condition of a tube than the emission type tester because it measures the amplification ability of the tube under simulated circuit conditions. The transconductance is measured and then compared with the ratings of the tube manufacturer. The meter scale of this type of tube tester is usually calibrated to indicate the transconductance (G_m) either directly in micromhos or indirectly in terms of good, weak, or bad. A voltage or power amplifier tube is considered defective when its transconductance decreases to 70 percent of the value stated in standard tube tables; the oscillator section of a converter tube is considered defective when its transconductance decreases to 60 percent of table values.

c. OPERATION OF A TYPICAL TUBE TESTER.—The tube-testing equipment the operation of which will be discussed in the text to follow, is a typical, general-purpose test equipment of the transconductance type. The Navy I-177 tube tester is representative of this type equipment.

(1) GENERAL ANALYSIS.—The front-panel controls on this tester adjust (or switch) the various potentials necessary for the testing of tubes. The tube data chart (book type) which is supplied with the equipment, lists the control settings for the various types of tubes generally encountered in the field.

CAUTION

Before the tube to be tested is inserted in the correct test socket, make certain that the front-panel controls are set to the positions listed for that type tube in the data chart. This precaution is necessary to prevent excessive voltages from being applied to the tube elements (especially the filament).

Figure 2-77 shows the over-all schematic diagram of a typical tube tester. This diagram may at first appear to be complicated, but it is easily understood if it is broken up into the circuits that provide the following functions and tests: the line-voltage adjustment and test, the short-circuit test, the noise test, the gas test, the rectifier test, and the quality test.

(*a*) THE LINE-VOLTAGE ADJUSTMENT AND TEST.—The line-voltage adjustment is necessary so that the line voltage applied to the primary of the transformer can be preset to an operating value of 93 volts (used as a test reference point), regardless of the variations caused by different tube loads or fluctuations in the a-c supply, which may range from 105 to 130 volts and still be adjustable. Depressing the LINE TEST button connects the meter of the tube tester to read the B-supply voltage. The test equipment is calibrated at the factory so that the meter pointer is exactly at 1500 micromhos (approximate center) when the voltage across the primary is 93 volts. Since various types of electron tubes draw different values of currents, a LINE ADJUSTMENT rheostat (connected in series with primary) is provided so that the primary voltage can be set to the designed operating voltage before any test is begun. A small protective lamp which will burn out on overload is connected in series with the primary of the transformer to prevent equipment damage.

(*b*) THE SHORT-CIRCUIT TEST.—The circuit utilized for the short-circuit test (figure 2-77) is similar to the basic circuit shown in figure 2-75.

CAUTION

The test for short-circuited tube elements should be made before any other test is attempted. If a short circuit is found, no further tests should be made, or the meter or other indicators on the instrument may be damaged.

By means of a rotary five-position switch labeled SHORT-TUBE TEST, the electrodes of the tube under test are switched in turn across a neon SHORTS lamp, which is connected in series with the secondary of the transformer. Shorted tube elements (and any other internal tube connections) complete the a-c circuit, causing both plates of the neon lamp to glow. Momentary flashes of the neon SHORTS lamp may be caused when the switch is rotated. These flashes are caused by the charging of the small interelectrode capacitances of the tube when the voltage is applied, and do not indicate short circuits. If the tube under test has a shorted element, the neon lamp will glow continually on one or more switch positions. Since the filament circuit and other internal tube connections will show up as short circuits in this test, the tube data chart should be consulted for pin connection information before interpreting the results of the test.

(*c*) THE NOISE TEST.—The noise test is used to check for intermittent shorts or microphonic noise. The circuit used is the same as that employed for the short-circuit test. See figure 2-67. In tests for noise, the antenna and ground terminals of a radio receiver are connected to the NOISE TEST receptacles. Any intermittent short between tube electrodes permits the a-c voltage from the power transformer to be applied momentarily to the neon lamp. The brief oscillation of this lamp contains various radio frequencies which are reproduced as audible signals in the receiver speaker. A less sensitive noise test can be made using a pair of headphones instead of the radio receiver. The tube should be tapped while it is being tested.

(*d*) THE GAS TEST.—The gas test circuit (figure 2-67) is similar to the basic circuit shown in figure 2-64. The value of the grid resistor used in the typical tube tester is 180,000 ohms. Two push-button switches, labeled GAS NO. 1 and GAS NO. 2, are used for this test. GAS NO. 1 button is first depressed, and the plate current reading on the meter is noted. Depressing the button marked GAS NO. 2 inserts the 180,000-ohm resistor into the grid circuit. If gas is present in the tube, the grid current that flows reduces the normal bias on the tube and increases the plate current measured by the meter. A tube with a negligible amount of gas produces an increase in plate current of less than one scale division when GAS NO. 2 button is depressed. An

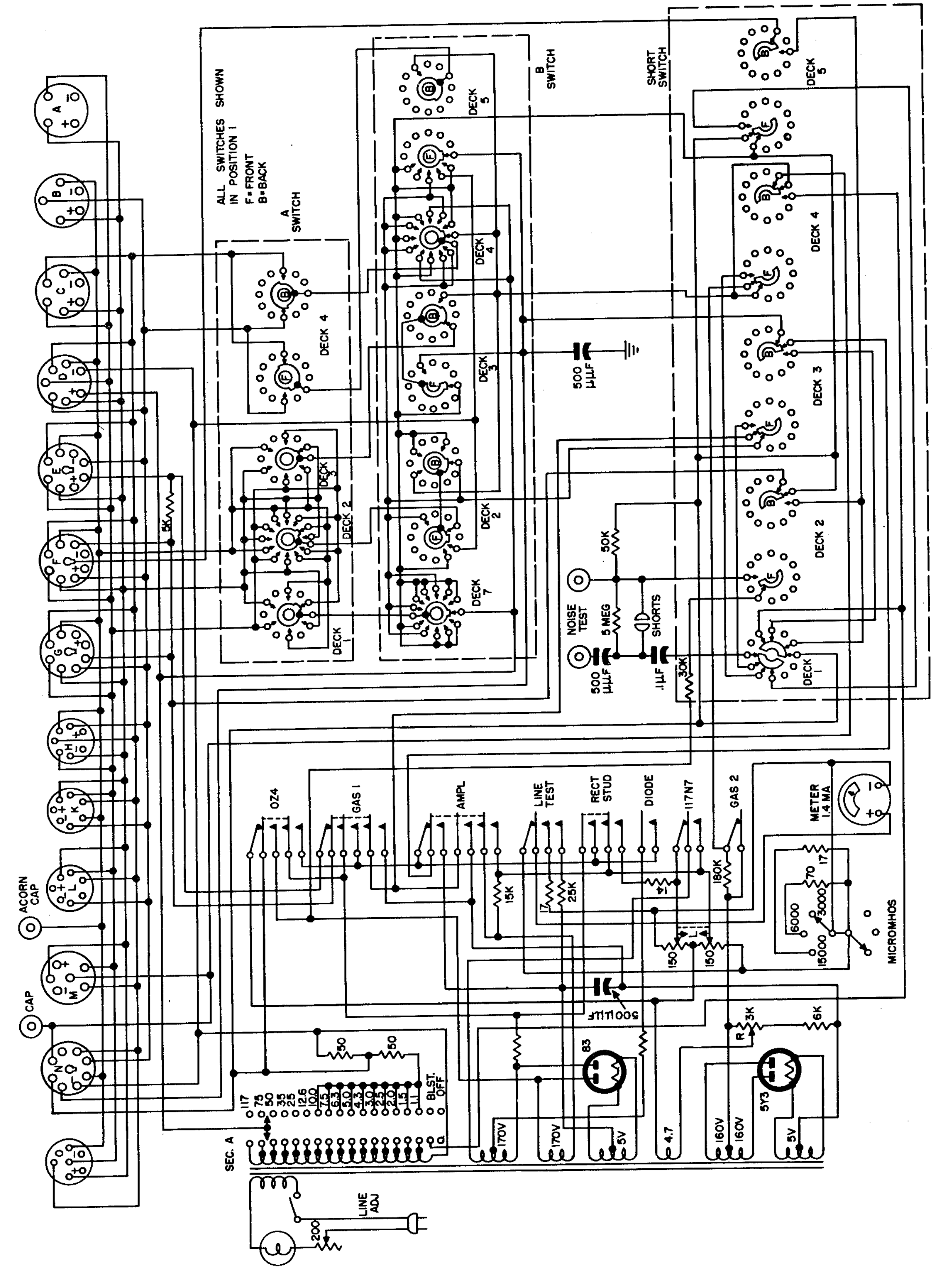


Figure 2-77. Over-all Schematic Diagram of a Typical Tube Tester

increase of more than one scale division indicates an excessive amount of gas in the tube.

(*e*) THE RECTIFIER TEST. — The circuit (figure 2-77) used for testing full-wave rectifiers, diodes, and OZ4 tubes is an emission test circuit, which is similar to the basic circuit shown in figure 2-72. An a-c voltage of definite value is applied to the tube under test, and the meter indicates the rectified plate current. The two sections of a full-wave rectifier are tested separately. The button for testing OZ4 cold-cathode rectifier tubes provides a higher a-c voltage than is normally used for heater (or filament) type rectifiers. The button for diode tubes provides a lower voltage than that used for regular rectifiers, and also inserts a protective series resistance.

(*f*) THE QUALITY TEST. — For the quality test using the good-fair-bad scale, or for the direct measurement of dynamic transconductance (in micromhos), the d-c grid bias for the tube under test is supplied by the 5Y3G rectifier tube, as shown in figure 2-77. The correct value of this grid bias is obtained when panel control R (3K potentiometer) is rotated to the setting listed, in the test data chart, for the tube being tested. An a-c voltage (4.7 volts rms), which is taken from a separate winding on the power transformer, is applied in series with the grid bias. This voltage causes the grid to deviate in positive and negative directions from the d-c bias level, thereby effecting the grid-voltage change (Δ E_g) required for a dynamic transconductance test. The plate voltage of the tube under test is supplied by the 83 rectifier tube. The meter which indicates the plate-current change (Δ I_p) is in the return circuit of the rectifier supply. Panel control L (dual potentiometer), which is shunted across the meter, is used to adjust the shunt resistance so that the meter pointer provides the correct indication on the good-fair-bad scale. For the direct measurement of transconductance, the panel switch labeled MICROMHOS places additional shunt resistors across the meter, providing three scale ranges in micromhos. The setting (listed in the tube data chart) for this switch is determined by the type of tube being tested. The operation of this circuit is the same as that of the basic circuit shown in part (B) of figure 2-73, which was discussed in paragraph 2-12.*a.*-(3)(*b*).

d. SUPPLEMENTARY ELECTRON TUBE INFORMATION. — The following discussion, which is based on material taken from field reports, is presented to provide the technician with specific information concerning electron tube failures and factors that affect tube life.

(1) ELECTRON TUBE FAILURES.—Experience has shown that tube failures may be roughly classified as follows: mechanical defects and gas within tube, filament (or heater) burn-out, change in tube characteristics, physical damage, and intermittent shorts. Mechanical defects and rise of gas pressure within the tubes are attributed to faulty construction and processing. Some of these defects cannot be detected by standard testing methods until the tubes have been in operation for some time. Filament burn-out may be caused by repeated sudden application of full voltage to the filament. Initial heating of the filament is nonuniform. As a result, mechanical stresses due to thermal expansion are set up, and these stresses weaken the filament structure and hasten its failure. Change in tube characteristics is a broad classification and covers decreasing emission, change in cut-off voltage, changing transconductance, etc. Such changes are usually the result of deterioration of the cathode structure, or formation of a cathode interface surface in the tube, or changes in alignment of the electrode parts. Physical damage is largely accidental. It includes such causes as breakage, bending of pins, and inadvertent application of excessive voltages. Intermittent shorts are caused mainly by foreign matter, such as lint within the tube assembly.

(2) ELECTRON TUBE LIFE.—Tubes that have operated for several hundred or a thousand hours with relatively stable characteristics are more reliable than new tubes just taken out of stock. In general, it is not advisable to replace all the tubes of a group after a predetermined number of hours without regard to their condition. In fact, if the tubes have operated for any appreciable length of time, the intervals between testing may be lengthened. However, certain tubes are notorious for limited operation, and in such cases periodic changing will prevent much trouble. The transmit-receive (TR) tube used in radar equipments is a good example of a tube which should be changed at regular intervals.

It has been found that by operating new tubes for 100 to 300 hours in a test rack prior to actual use, 80 percent of the tubes that would have failed early in electronic equipments were eliminated. For pre-operation a steady current may be passed through the tube so that the plate and screen operate between one-half and full rated dissipation. Such pre-operation reveals short-time changes of tube characteristics, improper emission, inherent mechanical defects, gassy conditions, warping or sagging of grid structures, poor welds, and cracked envelopes. Tubes which survive the first 300 hours with only minor changes in characteristics are considered "good risks" for several thousand hours.

Electron tube life can be increased if frequent on-off switching of the filament power is avoided. The inrush current of the cold filaments is many times the rated operating current.

SECTION 3
TESTING—TECHNIQUES AND PRACTICES

3-1. ELECTRONICS TESTING—GENERAL.

The term "testing," as used throughout this manual, was defined in paragraph 1-2, and is considered to consist of measurements, tests, and checks. When these measurements, tests, and checks are applied to electronic equipments (or systems), they may provide information which establishes an acceptable condition, or they may result in the exposure of undesirable conditions which exist in these equipments. In the former instance, the testing (and inspection) proves that the equipments are performing within tolerances, and results in establishing a form of maintenance which is preventive in nature. In the latter instance, the testing (and inspection) exposes conditions which are undesirable, and which must be corrected if the equipments are to perform as designed. The result of this testing establishes another form of maintenance which is corrective in nature. Thus, by applying both preventive and corrective maintenance, it is seen that electronic equipments are kept in continuous service at optimum or peak performances that are reasonably close to the standards set by the manufacturers.

a. PERFORMANCE TESTING. — Performance testing data, along with other general maintenance information for various electronic equipments, are available to technical personnel who are responsible for the operation and maintenance of these equipments. Currently (1954) being made available for some naval equipments are books entitled "Performance Standards." These performance standards are written to cover a particular naval equipment or system, and have been established to enable the technician to make an intelligent evaluation (comparison) of the operating capabilities of that equipment; at the same time they serve as a gauge for the measurement of equipment efficiency. The standards are designed to ensure that equipments operate at maximum efficiency at all times, and to reveal any change from this optimum performance, thus indicating the need for corrective measures. The information provided in these performance testing books gives the technician a step-by-step performance check, presented in convenient chart form, with all test connections and test equipment clearly indicated for each step. The performance standards are accompanied by a Maintenance Check-Off Book, which provides complete, detailed procedures, and data recording sheets that enable the technician to compare the equipment performance against the established standards. These books (POMSEE), and other available testing data are concise and self-sufficient within themselves, and deal with the requirements of a particular equipment or system. Performance testing is discussed in this paragraph to show the relationship between that type of testing and preventive maintenance, as a means of emphasizing that the final results may indicate the need for corrective maintenance. In the text to follow, both preventive and corrective maintenance will be discussed. Trouble shooting—considered as the principal part of corrective maintenance—will be analyzed in detail.

b. PREVENTIVE MAINTENANCE. — The best maintenance work is preventive in nature, potential failures being detected and corrected before they have a chance to develop. Preventive maintenance is defined as those measures taken periodically or when needed, to achieve maximum efficiency in performance, to ensure continuity of service, to reduce major breakdowns, and to lengthen the useful life of the equipment or system. This form of maintenance consists principally of cleaning, lubrication, and periodic inspections aimed at discovering conditions which, if not corrected, may lead to malfunctions requiring major repair.

(1) INSPECTIONS.—Inspections fall into two main categories. First, there is the regular visual inspection of the mechanical aspects of the equipments which is conducted for the purpose of finding dirt, corrosion, loose connections, mechanical defects, and other sources of trouble. Second, there are the functional inspections that are accomplished through periodic tests and through the less-frequent bench tests. To realize the most fruitful results from the regular functional inspections, a careful record of the performance data on each equipment must be kept. The value of these records will be demonstrated in a number of ways. Comparison of data taken on a particular equipment at different times reveals slow, progressive drifts that may be too small to show up significantly in any one test. While the week-to-week changes may be slight, they should be followed carefully, so that necessary replacements or repairs may be

made before the margin of performance limits is reached. Any marked variations should be regarded as abnormal, and should be investigated immediately. Another advantage in keeping systematic records of performance and servicing data is that maintenance personnel develop a more rapid familiarization with the equipment involved. The accumulated experience contained in the records furnishes a guide to swift and accurate trouble-shooting.

The actual work of testing and servicing, as well as that of recording performance data, should be done systematically. While a logical sequence of steps is required, this does not imply the rigid necessity of making only a step-by-step progression. Working within the over-all pattern of procedure, maintenance personnel should analyze the results obtained, to eliminate unnecessary steps.

c. CORRECTIVE MAINTENANCE.—Corrective maintenance consists of the location and correction of troubles whenever an equipment or system fails to function properly. The trouble may be corrected by mechanical or electrical adjustments, or it may be necessary to replace one or more parts. Failure Reports, are, as a rule, submitted when a defective part is replaced. These reports are important, because the statistics gathered from them may be used to determine the future stock spares requirements. These statistics may also be used to improve the design of equipments on future contracts.

(1) TROUBLE-SHOOTING. — Corrective maintenance is, for the most part, concerned with trouble-shooting, which can be further divided into two phases. The first phase is system trouble-shooting. It is based on the starting procedure, and is designed to locate the unit in which the trouble occurs. The second phase is unit trouble-shooting, and is designed to locate the trouble in the unit in which it occurs. In some cases it is possible to determine which unit is at fault without following the system trouble-shooting method to isolate the unit. Quite often it is impossible to determine which unit is at fault until the system method has been employed in whole or in part.

(*a*) TROUBLE ISOLATION.—When abnormal operation has been traced to a particular stage or to a functionally related group of stages, its cause must be further isolated and identified as due to a particular faulty component or group of components. To do this it may be sometimes necessary to disassemble the equipment, either in whole or in part. After disassembly, the trouble may be immediately apparent through a mere visual inspection, whereupon the trouble should be corrected by repair or replacement. If the trouble is not immediately apparent, a more detailed procedure should be followed to isolate and repair or replace the actual circuit component responsible for the failure. This procedure consists of tube checks, point-by-point resistance and voltage checks, waveform analysis, and finally, repair or replacement of the defective component.

(*b*) TUBE TESTING. — Electron-tube failures are responsible for the largest percentage of troubles that occur in equipments or systems. However, if a particular system uses a great number of tubes, it is obviously impractical, and not good policy, for a technician to attempt to locate faults by general tube checking. Only when the fault has been traced to a particular stage should any tubes be tested, and then only those associated with the improperly functioning circuits.

When replacing a tube in a circuit, note and record the positions of the equipment controls before changing the setting of any of them. Test the new tube for shorts and gas before inserting into the circuit. If adjusting the controls with the new tube in place does not correct the abnormal condition, return the controls to their original positions, and, unless a reliable tube tester shows the original tube to be defective, replace the old tube in the original circuit. After replacing a tube in a circuit, decide immediately whether or not to keep the old tube. If the tube is kept, it should be labeled so that it will not be replaced in the same socket. Do not change tubes indiscriminately, otherwise tubes whose exact age and condition are unknown (or uncertain) will accumulate. In many high-frequency circuits, the interelectrode capacitance of a tube is a significant portion of a tuned circuit; therefore, when tubes are changed, the tuning of the circuits may be upset. Thus, if too many tube substitutions are made, the unit may become misaligned.

(*c*) RESISTANCE MEASUREMENTS. —Defective components can usually be quickly located by measurement of the d-c resistance between various points in the circuit and a reference point or points (usually ground), because when a fault develops it will generally produce a change in the resistance values. Point-to-point resistance charts can be used advantageously at this time. The values given, unless otherwise stated, are measured between the indicated points and ground.

Before making resistance measurements, make sure that the power has been turned off to the equipment under test. An ohmmeter is essentially a low-range voltmeter and battery. If the ohmmeter is connected to a circuit which already has voltages in it, the pointer may be deflected off-scale, and the meter movement may be permanently damaged.

Discharge filter capacitors before making resistance measurements. This is extremely important when testing power supplies that are disconnected from their loads. If a capacitor discharges through the meter, the surge may burn out the

meter movement. Furthermore, contact with a circuit containing a charged capacitor may endanger the life of the person making the test.

(*d*) VOLTAGE MEASUREMENTS. — Since most troubles encountered in equipments and systems either result from abnormal voltages or produce abnormal voltages, voltage measurements are considered an indispensable aid in locating trouble. Testing techniques that utilize voltage measurements also have the advantage that circuit operation is not interrupted. Point-to-point voltage measurement charts which contain the normal operating voltages encountered in the various stages of the equipment are available to the technician. These voltages are usually measured between the indicated points and ground, unless otherwise stated. When voltage measurements are taken, it is considered good practice to set the voltmeter on the highest range initially, so that any excessive voltages existing in a circuit will not cause overloading of the meter. To obtain increased accuracy, the voltmeter may then be set to the designated range for the proper comparison with the representative value given in the voltage charts. When checking voltages, it is important to remember that a voltage reading can be obtained across a resistance, even if that resistance is open. The resistance of the meter (and the multipliers) forms a circuit resistance when the meter prods are placed across the open resistance. Thus, the voltage across the component may appear to be approximately normal, as read on the meter, but may be abnormal when the meter is disconnected from the circuit. Therefore, to avoid unnecessary delay in the trouble-shooting procedure, it is good practice to make a resistance check on a "cold" circuit (before applying power), to determine whether resistance values are normal.

1. PRECAUTIONS.—The following precautions are presented as general safety measures pertinent to the measurement of voltages, and should be adhered to by all personnel who are responsible for the maintenance of electronic equipment. It should be constantly borne in mind that all voltages are dangerous—especially voltages above 300 volts—and can be fatal, if contacted. When it is necessary to measure high voltages, the following precautions should be observed:

Connect the ground lead of the voltmeter first. While making measurements, place one hand in a pocket or behind the back.

If the voltage to be measured is less than 300 volts, place the end of the test prod on the point to be tested—which may be either positive or negative with respect to ground.

If the voltage to be measured is greater than 300 volts, proceed as follows: shut off circuit power, discharge any filter capacitors and temporarily ground the point to be measured, connect (clip on) the proper test lead to the high-potential point, move away from the voltmeter, turn on the circuit power, and then read the voltmeter. Do not come in contact with any part of the equipment while the power is on. This is particularly important when the voltage under measurement is across two points, both of which are above ground potential. If an electronic voltmeter equipped with a polarity reversing switch is to be used, refer to WARNING in paragraph 2-3.*a*.(2) (*b*)*3*.

2. EQUIPMENT LOADING EFFECT. —If the internal resistance of the voltmeter and multiplier is approximately comparable in value to the resistance of the circuit under test, it will indicate a considerably lower voltage than the actual voltage present when the meter is removed from the circuit. For a discussion of the effects of voltmeter loading, refer to paragraph 2-3.*a*. (2) (*a*). The sensitivity (in ohms-per-volt) of the voltmeter used to prepare the voltage charts is always given on those charts; therefore, if a meter of similar sensitivity is available, it should be used, so that the effects of loading will not have to be considered.

(*e*) WAVEFORM COMPARISON.—The measurement and comparison of waveforms is considered to be a very important part of the circuit analysis used in trouble-shooting. In some circuits, for example, pulse circuits, waveform analysis is indispensable. Waveforms may be observed at test points, shown in the waveform charts which are a part of the maintenance literature supplied for the equipment. It should be noted that the waveforms given in instruction books are often idealized and do not show some of the details which are normally present when the actual waveform is displayed on an oscilloscope. By comparing the observed waveform with the reference waveform, faults can be localized rapidly. A departure from the normal waveform indicates a fault that is located between the point where the waveform is last seen to be normal and the point where it is observed to be abnormal. For example, if a waveform is observed to be normal at the grid circuit of a stage, and abnormal at the plate circuit of the same stage, this indicates that the trouble lies in that stage or possibly the input of the following stage. When the waveforms associated with a multivibrator, a blocking oscillator, or a similar circuit are observed to be abnormal, replace the associated tube before making any further tests. If the replacement tube does not provide the correct waveform, reinsert the original tube.

If there is no trouble present in an equipment or system, a waveform observed at a point in the equipment should closely resemble the reference waveform given for that test point. The reference waveforms supplied with maintenance literature are the criterion of proper equipment performance. However, test equipment characteristics or

usage can cause distortion of the observed waveforms, even though the equipment or system is operating normally. Several of the most common causes of these conditions are summarized as follows:

The leads of the test oscilloscope may not be placed in the same manner as those of the oscilloscope used in preparing the reference waveforms, or the lead lengths may differ considerably. This is particularly significant in the case of shielded test leads, where the capacitance per unit length is a factor.

A type of test oscilloscope having different values of input impedance, different sweep durations, or different frequency response may have been used.

The equipment operating (and servicing) controls may not have settings identical to those used when the reference waveforms were prepared. This condition is normally to be expected when servicing adjustments are made in terms of their effect on the shape or amplitude of an observed waveform.

The vertical or horizontal amplitudes of the reference and test patterns may not be proportional. This will produce apparent differences between the waveforms when actually there is no difference.

Whether or not a minor waveform discrepancy may be disregarded depends upon the type of circuit being traced. A minor discrepancy is not regarded as significant unless the nature of the discrepancy, in consideration of the circuit under test, indicates faulty operation of the equipment. In general, time should not be wasted in searching for faults when relatively minor differences are detected between the reference waveforms and those obtained by test.

3-2. EQUIPMENT MAINTENANCE—GENERAL.

Under the present system of organization aboard ship, the basic responsibility for the maintenance of electronic equipments rests with the department that operates the equipment. It is obvious that many maintenance operations or procedures are beyond the capacity of the personnel assigned to the operating department, and that close liaison between that department and the Electronic Repair Division must be effected. Some equipment records are a joint responsibility shared by both the operating and maintenance personnel. Operators in constant contact with equipment should be able to recognize and report any signs of abnormal operation—unusual sounds, flashes, or odors arising from the equipment. Electronics technicians should study and constantly refer to the available maintenance publications covering the equipments installed in the ship. They should stand ready to answer questions about equipments, and to outline the various steps necessary to correct nonexistent but possible troubles. Electronic history cards, which have replaced the earlier equipment logs, must be kept as required by the electronics officer.

a. RADIO RECEIVING EQUIPMENT.—Naval communication receivers are composed of a series of selective r-f and a-f circuits, each stage of which is designed to refine and amplify the output of the preceding stage. The lowered efficiency of any one tube usually results in lowered over-all efficiency of the receiver. The sensitivity of the receiver may also be decreased by the misalignment of the successive circuits, each of which may function in a suitable manner as a unit. The sole function of a communications receiver is to receive (in a selective manner) a faint signal; therefore, an objective over-all test on sensitivity is the most significant single check that can be made of the condition of a receiver.

Some receivers are provided with a built-in output meter, others have an output meter equipped with a cord and plug to facilitate testing. The only other requirement for a sensitivity check is a standard signal for the excitation of the receivers on the various bands. During radio silence this signal may be provided by a calibrated signal generator with a dummy antenna coupled directly to the receiver input. At land stations and at sea, when it is permissible to operate transmitters, the output of the signal generator may be fed into a central radiating antenna at the station (or on the ship) and receivers may be calibrated from their own installed antennas. Any decrease in sensitivity should be corrected as soon as possible by following the appropriate remedial procedures discussed in this section. When using this method, use a megger before starting the tests, to check for proper operation of both the radiating and the receiving antennas.

In addition to periodic checks on sensitivity, routine physical inspections must be made of the receiver and accessory units. Lubrication and cleaning schedules recommended by the manufacturer must be followed. Tubes should be tested sparingly, because frequent insertion and removal weakens socket contacts and causes noisy (or intermittent) operation. Electron-tube life extends to several thousand hours; therefore, in equipment which is continuously operated and on which periodic sensitivity tests (or operation records) are made, tubes should be checked only when poor performance indicates such a need. When tubes are replaced in r-f circuits, the circuit should be realigned, if necessary to achieve normal sensitivity. Before new tubes are used, it is good practice to check them on a tube tester of the transconductance type.

Methods of adjustment and servicing are discussed in detail in instruction books supplied with each equipment. Technicians should proceed

methodically in locating receiver faults by first testing the most accessible (or vulnerable) parts. Previous experience and trouble-shooting charts aid in isolating the trouble. While the receiver is on the test bench, all parts should be thoroughly cleaned and inspected so that parts close to failure may be detected beforehand. Since receivers may operate for many years with reduced sensitivity before a complete failure occurs, a long-term schedule for overhauling must be established for each receiver.

b. RADIO TRANSMITTING EQUIPMENT.—Because the operating procedure for most radio transmitters calls for continuous tuning and retuning, tube currents are automatically measured by the indicators provided. If these readings are periodically recorded, the cumulative record bears the same relationship to the transmitter as a sensitivity check does to the receiver. When the emission of a large tube falls to 80 percent of normal rating, it should be replaced. Because it is possible for large tubes to become soft (gassy) when stored for a considerable time, they should be rotated with tubes of the same type in spare storage so as to maintain three sets of large tubes in good condition at all times. In some cases the residual gas can be removed by absorption into the filament if the filament voltage is operated at a slightly higher value than normal for a period of several hours with no voltage applied to the plate and screen.

Ventilation and dust conditions present a greater problem in transmitters than they do in receivers, principally because there is more heat to be dissipated. Because dust forms a film which absorbs moisture, the insulation resistance is lowered to a point at which flash-over can occur. Therefore, cleaning periods must be initiated and regularly followed. These periods will vary for different locations. Insulators must be wiped, corroded metal parts cleaned, and arc-overs repaired. It is possible to detect poor contacts by inspecting for evidences of local overheating (or arcing). Such contacts must be thoroughly cleaned and tightened. Likewise, it is important that the antenna connections be regularly inspected and cleaned.

During radio silence the proper tuning of transmitters presents a problem, because an appreciable amount of r-f energy must be prevented from radiating. Previous tuning of the transmitter, while the ship is at a base, through a great number of operating frequencies and accurate logging of all the dial readings eliminates the need for operation during radio silence. Interpolations are used if exact frequencies are not required. Oscillator frequencies which are not crystal-controlled are set by means of an appropriate frequency meter.

When the procedure mentioned above is not feasible, the following plan may be used if the transmitter is enclosed in a steel room with metal doors and port covers. Disconnect and ground all antenna leads entering the compartment. A receiver located in another part of the ship should be tuned to ascertain whether there is any r-f leakage from the compartment. Preliminary stages may be tuned and neutralized while the power-amplifier stage is de-energized. To tune the power-amplifier stage, the antenna is ungrounded and connected to the transmitter which is de-energized, and a receiver that is pretuned to the desired frequency is coupled to the power-amplifier stage. Tuning is accomplished by varying the tuning of the antenna, transmission line, and the power-amplifier stage until a maximum random noise is measured on the signal-strength meter of the receiver. Transmitter tuning under conditions of simulated radio silence should be practiced by technicians and operators until they have demonstrated proficiency in this duty.

c. COMMUNICATIONS EQUIPMENT—SUMMARY.—The testing discussed up to this point under the title of EQUIPMENT MAINTENANCE—GENERAL applies broadly to most communications equipments but specifically to radio receivers and transmitters, and provides an introduction to the paragraph, which follows immediately in section 3, titled RECEIVER TESTING. All of the necessary tests, measurements, and checks required for general equipment maintenance are provided in detailed discussions accompanied by test methods and procedures. TRANSMITTER TESTING is covered next stressing frequency and power measurements as well as some additional measurements made at or near a transmitter.

d. ELECTRONIC SYSTEMS.—Information on the testing of both radar and sonar systems is provided in section 3. It is important to stress performance testing if proper preventive maintenance techniques are to be acquired. It is assumed that the technician is familiar with the fundamentals of radar and sonar operation; however, by way of review, a short discussion of each system is given.

3-3. RECEIVER TESTING.

a. INTRODUCTION.—The material included in the following paragraphs is intended primarily for the checking of receiver condition in the field. It is not a complete guide to laboratory or bench testing. Rather, it is aimed toward aiding a qualified technician to decide whether or not an equipment should be taken out of service for realignment, minor repair, or return to a base for overhaul.

Prior to making any tests with a signal generator, the receiving equipment should be checked to ascertain that all vacuum tubes, rectifiers, and other replaceable elements with limited life cap-

ability are in good condition. All plug-in or friction-contact type connections should be checked for noise and contact, by removal and replacement a number of times, or by working them back and forth (as in the case of variable gain controls). Also, power-line voltage and frequency, battery condition, etc, should be checked before proceeding with the measurements. The signal generator used should be of a type recommended by the equipment instruction book or other qualified source of such information.

b. SENSITIVITY (GENERAL).—The one measurement which provides maximum information about receiver condition in field operation is that of sensitivity. This measurement ordinarily requires the application of an input signal of variable voltage (which is accurately known by calibration) to the antenna terminals of the receiver, through an impedance which approximates that of the antenna with which the receiver is designed to be used. Any external impedance which is added to the signal-generator impedance to simulate the antenna impedance is usually known as a dummy antenna. It insures that the signal current in the input circuit of the receiver is the same as would appear with the known signal induced in an ideal receiving antenna, and it also insures that the input circuit of the receiver is "loaded" the same as it would be by an ideal antenna.

(1) DUMMY ANTENNAS.—In the 15 to 30,000-kc range, a typical standard dummy antenna for high-impedance-input receivers consists of a 20-microhenry inductor shunted by a series-connected 400-micromicrofarad capacitor and a suitable 400-ohm resistor, with the shunt combination in series with a 200-micromicrofarad capacitor, figure 3-1. This unit should be enclosed within a properly designed grounded shield and used with a signal generator having a resistive output impedance not exceeding 50 ohms. This dummy antenna "looks" like a 200-micromicrofarad capacitance at low frequencies, is a complex impedance in the 1-mc region, and "looks" like a 400-ohm

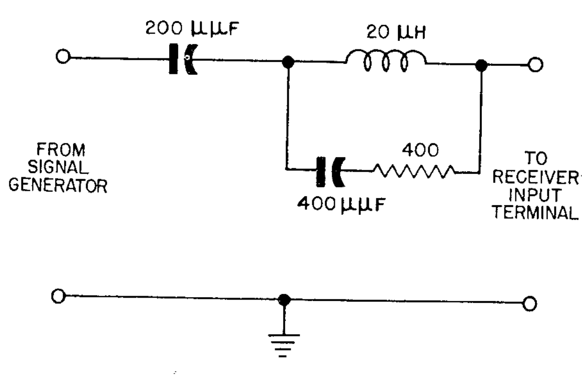


Figure 3-1. Standard Dummy Antenna Circuit

resistance at frequencies of 2 mc to 30 mc. For the measurement of low-impedance-input receivers of 50 to 70 ohms nominal impedance, a signal generator with a 50-ohm output may be directly connected, without the use of an external dummy antenna. Other generator impedances may require special dummy-antenna networks to load the generator and the receiver properly while allowing the equivalent induced antenna voltage to be accurately known.

(2) CONDITIONS FOR SENSITIVITY MEASUREMENT.—For measurement of sensitivity, the receiver is adjusted for the type of reception desired, and facilities such as tone controls or audio filters, agc, silencer, noise limiter, etc, are placed in or out of operation as required or are set at appropriate control positions, as discussed later. The power-line voltage applied to the receiver should be well within the normal recommended operating range. The receiver output terminals should be properly loaded. At the headphone or audio-line terminals, unless otherwise specified in the instruction book for the equipment, the load should be a 600-ohm noninductive resistor (such as one of the composition type), capable of continuously dissipating the maximum receiver audio power output that can be produced at these terminals. High-impedance headphones may be used in shunt with the load for monitoring the output. Low-impedance phones may load the output appreciably and may have to be removed when data are being taken. The output voltage should be measured with a high-impedance audio voltmeter, capable of accurate indication from 0.1 volt to 100 volts, that will not appreciably load the output circuit. Although some receivers are equipped with audio-output meters, the meters provided may not indicate required standard noise levels with sufficient accuracy.

c. C-W (A-1) AND FACSIMILE (A-4) SENSITIVITY.—For c-w (A-1) reception sensitivity measurements, some means must be provided to set the output beat note of the receiver to the standard 1000-cps frequency with reasonable accuracy (about 1000 ±50 cps). In some receivers, the 1000-cps "sharp" audio filter provided has a bandwidth narrow enough to allow satisfactory adjustment of the beat note by centering the tone in the passband. The 1000-cps internal tone modulation frequency of most signal generators is also accurate enough and can be zero-beat against the output beat note. Alternatively, the output of a calibrated audio oscillator and that of the receiver may be fed independently to the deflection amplifiers of an oscilloscope to give the Lissajous pattern typical of synchronous waves for establishing the output frequency.

For determination of both keyed c-w and facsimile reception (A-1 and A-4) sensitivity, the

c-w (beat-frequency) oscillator should be on and the receiver audio gain should be set at maximum, with agc, silencer, noise limiter, and output limiter turned off. If not otherwise specified in the receiver instruction book, audio filters or tone controls should be set for maximum audio range. The antenna trimmer normally should be peaked at the high-frequency end of each band, and not reset at other frequencies. The signal generator is used unmodulated. Following these initial adjustments, the r-f gain control is adjusted to produce 60 microwatts of noise (0.19 volt across 600 ohms) with the receiver tuned to the desired frequency but with no input signal applied from the signal generator. The signal (carrier only) is then applied, and is tuned as nearly as possible to center on the noise of the over-all r-f passband of the receiver, with the c-w oscillator frequency control adjusted to the side of zero beat that produces the higher output with a 1000-cps beat note. The input-signal voltage is then adjusted to produce 6 milliwatts output (1.9 volts), resulting in +20 db output signal-to-noise ratio within 0.1 db. The receiver sensitivity, in terms of input-signal voltage, is then read from the signal-generator voltage calibration (see signal-generator instruction book to interpret voltage readings).

d. M-C-W (A-3) SENSITIVITY.—M-C-W (A-3) reception sensitivity measurement requires the application of a carrier modulated 30 percent at 1000 cps. The r-f gain control should be set at maximum, with agc on and the c-w (beat-frequency) oscillator off, unless this condition is automatically established by a reception selector control (provided on some receivers). All other controls except the a-f gain should be set as indicated for c-w (A-1) reception. Both the input-signal level and the a-f gain control are then progressively adjusted until the receiver output noise level is 0.6 milliwatt (0.6 volt) with signal-generator modulation off, and the signal-plus-noise output is 6 milliwatts with modulation on, which produces +10 db ratio of output signal-plus-noise to noise (10.4 db signal-to-noise ratio). The receiver sensitivity, in terms of input voltage, is then read from the signal-generator voltage calibration.

e. M-C-W (A-2) SENSITIVITY.—Tone-modulation (A-2) reception sensitivity should be measured under the same conditions and using the same procedure as for A-3 reception sensitivity, except that the a-f gain is set at maximum with agc off, and the r-f gain control and signal-generator output voltage are varied to produce standard sensitivity conditions. Also, the generator should be modulated 100 percent at 1000 cps, with standard output of 6 milliwatts signal plus noise and noise output of 60 microwatts for generator modulation off (20 db output signal-to-noise ratio).

If the available signal generators cannot be used modulated 100 percent because of excessive frequency modulation or because of other limitations, an approximate sensitivity measurement may be made by employing 30-percent modulation to produce 6 milliwatts output with 10 db output signal-plus-noise to noise ratio. This procedure may give somewhat erroneous results, as detector modulation distortion or modulation clipping by built-in noise limiters may be much less at 30-percent than at 100-percent modulation of the carrier.

f. FSK SENSITIVITY.—The receiver, FSK converter, and teletypewriter must all operate satisfactorily to produce proper copy in FSK operation. If the receiver checks satisfactorily for c-w (A-1) sensitivity, only the additional switching for FSK reception and any special FSK filters in the receiver could produce poor FSK operation, so far as the receiver proper is concerned. Therefore, the receiver may be checked for FSK sensitivity by initially checking its standard c-w sensitivity. If this proves to be normal, switching to FSK operation will allow the output beat frequencies and audio output level to be checked to insure that they meet the requirements of whatever audio-type FSK converter is employed.

The output which the receiver can produce for an i-f type converter (if this facility is provided) may be checked with an electronic voltmeter capable of good accuracy at the intermediate frequency, with a range of 0.001 volt to at least 10 volts. The receiver and converter instruction books should be consulted for standards of receiver output in this case.

g. RESERVE GAIN.—Reserve gain for all types of reception may be determined by measuring the ratio of noise output at standard gain (the gain condition used in measuring standard sensitivity) to noise output at maximum gain, provided maximum gain does not produce any substantial degree of output overload or saturation. If saturation is approached or reached at maximum gain, the setting for standard gain should be noted, and the reserve gain determined with the aid of a gain control calibration curve, which can be obtained by subsequent measurement.

h. GAIN VARIATION WITH CHANGE OF FREQUENCY.—Gain variation over each band for any condition of reception may be determined by adjusting for standard gain (as for sensitivity measurements) at the high-frequency end of each band, and then noting the input-signal voltage required at various frequencies over the band to produce the same 6-milliwatt 1000-cps output.

i. OVER-ALL SELECTIVITY (GENERAL).—The term "over-all selectivity" usually refers to the frequency selectivity of a receiver as measured from (and including) the antenna to the input terminals of the final detector. It does not normally include any elements of the audio system.

The over-all selectivity of a superheterodyne

receiver may be quite difficult to measure accurately with the equipment likely to be available in most operating installations, especially at frequencies above 1 mc. If the lowest signal frequency is at least several times that of the lowest intermediate frequency used in the receiver, the over-all selectivity is very likely to be practically the same as the lowest i-f selectivity. In such instances, the i-f selectivity curve may suffice and is much easier to measure.

j. NARROW-BAND RECEIVER SELECTIVITY.—For receivers with r-f or i-f bandwidth of less than about 5 kc at 6 db down (e.g., VLF and LF receivers), the measurement can be made as follows: The receiver should be adjusted for standard m-c-w (A-2) sensitivity conditions (agc off), with a high-impedance d-c voltmeter connected to read the voltage across the final-detector diode load. (It may be necessary to connect a 1-megohm isolating resistor between the "high" end of the diode load and the "high" lead of the voltmeter to prevent regeneration or other undesirable effects.) The signal generator is used unmodulated, and the signal voltage is increased from standard input in steps of about 1.4, 2, 3, 5, 10, 100, and 1000 times the standard input, in turn. At each step, the frequency of the signal is adjusted to produce the same detector diode voltage as previously obtained with standard input at resonance. The signal-generator frequency-vernier dial reading is taken for each step at both sides of resonance. The reading recorded should always be obtained by approaching from the same direction of dial rotation for all readings, to minimize error resulting from signal-generator dial backlash. The signal-generator frequency dial can be calibrated with higher precision than afforded by its markings in the range covered, by first noting the vernier-dial settings for the two frequency-dial markings nearest the limit frequencies of the selectivity curve data and then dividing the difference in frequency by the corresponding number of vernier divisions to obtain kc per division. A curve can be plotted of "times resonant input voltage" on semi-log paper (or "db above resonant input" on linear paper) against "kc off resonance" on a linear scale. The points of greatest interest are usually those defining the 6 db down and 60 db down bandwidths, which also determine the 60/6 db bandwidth ratio (or selectivity ratio).

k. SELECTIVITY OF WIDER-BAND RECEIVERS.—With receivers having 5 kc or more bandwidth at 6 db down on the selectivity curve, selectivity measurements may be made using a modulated carrier, provided that the rate of attenuation at the skirts of the curve is not too high (not more than about 6 db per kc). This means that, in general, TRF and single-conversion superheterodyne receivers designed for operation above 500 kc may be measured with a carrier modulated 30 percent by a 400 or 1000-cps tone. The procedure is the same as for unmodulated carrier selectivity measurement (as above), with the same receiver conditions, except that the output measurement is made at the audio output terminals of the receiver, just as for m-c-w (A-2) sensitivity (agc off). The audio output is maintained at standard level, as the input-signal frequency is varied, by adjustment of the signal-generator carrier output voltage.

l. I-F SELECTIVITY.—I-F selectivity may be measured in the same manner as over-all selectivity, except that it may be desirable to disconnect the input-signal circuit from the preceding frequency converter (mixer) to prevent that circuit from loading the signal generator. It will then usually be necessary to provide a grid-return resistor for the mixer (about 10,000 ohms), as well as a coupling capacitor (about 1000 $\mu\mu$f) from the mixer input grid to the signal-generator output, in order to prevent d-c return through the generator system. The oscillator should be disabled, by removing the oscillator tube or its supply voltages, if it appears to produce interference with the measuring signal. If this is done, the mixer output impedance will be changed somewhat, producing some change in i-f selectivity; however, the change is usually of a minor nature.

m. PRIMARY IMAGE REJECTION.—The primary image rejection ratio provides a simple criterion of the preselector (front-end) alignment condition. To determine the primary image ratio, the receiver is first adjusted for standard m-c-w (A-2) sensitivity conditions. The signal generator is then tuned to produce maximum response at the primary image frequency (twice the if. away from resonance, on the same side as the oscillator), and the input-signal voltage is adjusted to produce standard output. The ratio of the image input voltage to the standard sensitivity input (usually expressed in db) is the image rejection at that desired signal frequency. If the values obtained for this ratio over each band are within 3 db of the instruction book values and the sensitivity is normal, the front-end alignment is probably good.

n. TUNING-DIAL CALIBRATION.—Tuning-dial frequency calibration can be checked against any signal whose frequency is accurately known, such as that of radio station WWV and standard AM, FM, and TV broadcast stations. Some receivers have built-in crystal calibrators which give signals spaced throughout the working range of the receiver. If none of these signals are available, it will be necessary to obtain a heterodyne frequency meter such as the model LR, the output of which may be fed to the receiver antenna terminals and tuned in as an unmodulated c-w signal. With any of these means, the tuning dial error should be carefully observed. If the error is exces-

sive (more than about ±1 percent) and shows a definite progression with frequency, the receiver may require realignment.

(1) TUNING-DIAL BACKLASH.—Tuning-dial backlash is usually best determined in the c-w (A-1) reception condition, by first tuning in a c-w signal to receiver resonance with rotation of the dial in one direction, and adjusting the beat-frequency oscillator, on the side of zero beat that gives the greater output, until a 1000-cps beat note accurate with ±5 cps is obtained. The vernier tuning dial (if provided) is then read as accurately as possible, or the tuning knob is marked in some suitable way. Following this, the signal is again tuned in, approaching it this time from the opposite direction of dial rotation, until the same 1000-cps indication is obtained on the same side of zero beat as before. The difference in vernier-dial divisions or in angular position of the tuning knob is the backlash.

Zero-beat output from the receiver might be used as a reference for this measurement instead of 1000 cps, which would allow dispensing with the oscilloscope and audio oscillator. However, the audio response of most receivers at very low frequencies is not good, which usually makes accurate determination of zero beat by ear or output meter quite difficult.

o. RESONANT OVERLOAD.—The resonant overload characteristic (desired output vs signal carrier input voltage) should be determined with the receiver adjusted for standard sensitivity conditions for the type of reception desired (A-1, A-2, etc). The receiver output voltage for increasing values of signal-generator input from 0.1 microvolt to maximum is recorded. In addition, in m-c-w operation, the output noise level at each input-signal level with modulation off but carrier on should be recorded. These readings, when plotted on log-log paper, can be interpreted to indicate linearity of receiver gain, residual hum and hum modulation, etc. If resonant overload curves are obtained for different audio-gain-control (acg on) and output-limiter-control (agc off) settings, respectively, the capabilities of the a-g-c system and of the limiter may be determined (for steady-state signal conditions). If resonant overload curves are obtained at different silencer or squelch-control settings over the working range, silencer characteristics and effectiveness of operation may be determined. These may be compared with report or instruction-book data on these characteristics.

p. FREQUENCY STABILITY.—Frequency stability with mechanical stress caused by inclination, shock, and vibration may be noted by observation of the receiver while it is subjected to these conditions during use, or various surfaces of the receiver may be pressed upon or pounded with the hands in bench tests. In either case, the effect of mechanical displacements of the receiver on the pitch of the output beat note at various receiver frequencies should be observed under the conditions of c-w (A-1) reception. Relative comparisons can be made between different receivers of the same model by this procedure, if it is suspected that a defect has developed in one of them. Similar simple tests can be made for microphonic elements.

Warm-up frequency drift may be measured by setting a Model LR or similar frequency meter to give a 1000-cps beat-note output from the receiver (in A-1 reception condition) when the receiver is first turned on. Then, as the receiver drifts, the frequency meter is returned at intervals to produce this same beat note, and the new frequency reading is recorded each time until the drift has essentially stopped. If the drift is small, the frequency meter may be left fixed, and the change in beat-note frequency observed instead. If the receiver is not designed for A-1 operation, a signal that will heterodyne with the if. may be injected into the final detector through suitable loose coupling means, and the frequency meter used as directed above.

Frequency stability with gain change may be determined by feeding the maximum unmodulated carrier output of the signal generator to the receiver (as adjusted for c-w (A-1) or FSK (agc off) reception), and then turning the r-f gain control from maximum gain down until the output signal can just be heard. The change in output beat-note frequency should be less than 100 cps with a well-designed receiver intended for signals below 30 mc, and less than 10 cps below 1 mc. A similar test for receivers not designed for the above modes of operation can be made by using a heterodyning voltage injected into the second detector as described above. For such receivers, greater frequency changes are usually tolerable (up to 10 percent of the 6-db down bandwidth of the over-all selectivity curve).

Frequency stability with input-signal voltage change may be determined by noting the beat-note change during a c-w (A-1) or FSK (agc off) resonant overload measurement made as previously described. The same beat-note tolerances as above will apply. This test may be made on receivers without beat-frequency oscillators by using auxiliary beating means as described above.

q. NOISE (INTERFERENCE) MEASUREMENTS.—Because of the increased number of electronic and electromechanical equipments required to meet modern military needs, the elimination or suppression of noise and radio interference produced by these equipments has assumed greater importance. Interference, it should be remembered, not only may restrict or prevent vital communications, but also may divulge the position of a task unit to the enemy during periods of radio silence.

Various test equipments called radio test sets or noise meters are available to the technician to aid in measuring and locating interference. However, a systematic and logical procedure must be followed to locate the offending noise. If the receiver antenna system is introducing the interference, disconnecting the antenna at the receiver input terminals will generally cause the noise to disappear or abate considerably. Noise being conducted through the power line will, of course, not be affected by the above procedure, except for that type of interference that requires cross modulation with a carrier to make itself evident. Also, noise generated within the receiver itself will not be altered. The above test is important when the sound of the interference appears similar to tube noise or power-supply hum. Caution must be observed when using this method on receivers that operate on the higher frequencies since a short length of antenna lead (or even an unshielded circuit) may be sufficient to pick up considerable interference when the source is close to the receiver.

When it is established that the antenna is picking up interference, it is necessary to determine the exact source. An effective method is to turn off all equipment operating in the vicinity; if the interference ceases, each individual equipment can then be restarted one at a time until the equipment which causes the interference to reappear is located. It is more advantageous to begin with all equipments shut down, rather than stopping individual equipments with others running, because of the possibility that a weak source may be masked by a stronger source.

A common method of locating a noise source using a noise meter is to move about the suspected area with the instrument and observe the intensity on the indicating meter, or listen to the audio level with a headset. Since noise sources usually have a large gradient, it is often possible to proceed to the source of interference by walking in the direction of increasing readings. After locating the offending equipment, it is necessary to determine the particular part of the equipment that is responsible for the disturbance. This is accomplished, if possible, by judicious use of individual switches (or other means of disconnection) on various units of the equipment and by the use of probe antennas. Two types of probe antennas are available: the magnetic type, consisting of a small loop for magnetic pickup, and the electrostatic type, consisting of a length of shielded cable with about 5 inches of the insulated (but shield stripped) inner conductor extending for electric pickup. The shield covering the leads to the probe should be connected to the case of the noise meter. A probe antenna is effective only when brought close to the source, and is a great aid in locating the actual source.

A test equipment of the type used to measure radio interference is essentially a sensitive portable receiver covering a specified range of frequencies and capable of measuring noise levels and field intensities. (A representative type is exemplified by Radio Test Set AN/URM-6.) This type may be used as an r-f voltmeter to measure a voltage between two points. It differs from a conventional receiver, however, in two respects: (1) a time delay is introduced into the a-v-c circuit so that the output meter indicates the noise voltage in terms of the peak (or quasi-peak) value, which is more significant than the average, and (2) the gain of the receiver is adjustable to previously calibrated levels, to ensure uniformity of measurement on all frequencies. A calibrating signal source is included in the equipment for the latter requirement. For the former requirement a standard noise source is provided and is usually built into the test equipment. Briefly, it consists of a diode operating at saturation, the shot-effect noise of the tube providing a sufficiently constant source of noise for calibration purposes. To maintain space current in the tube at saturation, a filament control (rheostat) is provided. For calibration procedure the instructional literature that accompanies each test equipment should be followed in detail. In general, it should be noted that the above test equipments require extreme care and careful maintenance to provide reliable service. Realignment and calibration are necessary at frequent intervals, especially if the equipments are often transported from place to place.

In conclusion, it should be stressed that equipments which normally do not produce noise, may do so when defective or in bad condition. This is particularly true of rotating or vibrating machinery. All commutators, slip rings, brushes, and brush holders must be in good condition. All normal ground connections to the frame or housing should be clean and tight. Movable contacts such as switch points, relay contacts, etc, should be clean and properly adjusted for minimum arcing. All shielded connections and bonding must make clean and tight electrical contact. Therefore, when the source of interference is located, corrective maintenance should be considered as part of the job of eliminating noise and interference.

3-4. TRANSMITTER TESTING—FREQUENCY MEASUREMENTS.

The measurement of transmitter frequency is important for a number of reasons. One reason is that measurement is the only way of determining whether there is compliance with Naval regulations. These regulations concern harmonic frequencies and sidebands, as well as specifying tolerances for the assigned frequency of transmission. Frequency measurement is equally vital in the laboratory, where the technician as well as the engineer is required to determine frequency on

many occasions. In the field, a technician is often called on to tune a transmitter to some desired frequency. Even if a definite frequency is not stipulated, the technician must confine the operation of the transmitter to the proper frequency band. In addition, it is often necessary for a technician to adjust a multiplier stage to the correct harmonic, or to measure the harmonic output of a transmitter. Lastly, when a parasitic oscillation exists, a measurement of its frequency is usually necessary.

a. FREQUENCY TESTING EQUIPMENTS.—There are a large number of frequency-measuring equipments. Some have been discussed in section 2, paragraph 2-7, such as wavemeters, the heterodyne frequency meter, and the resonant-coaxial-line frequency meter. Under the title of this paragraph, practical methods and techniques for measuring radio frequencies will be discussed in greater detail.

b. CALIBRATED RECEIVER METHOD.—If no specific frequency-measuring equipment is available, it is possible to use a calibrated receiver and achieve surprisingly accurate measurements. Well-designed receivers are accurate to better than 0.04 percent. Factory-calibrated receivers may be even more accurate. Greater accuracy is achieved if the transmission is unmodulated. If maximum response in the receiver is indicated by a carrier-actuated tuning indicator, the beat-frequency oscillator in the receiver should be turned off. When a stable bfo is available, a procedure that produces even more accurate results is possible. First, the bfo is adjusted to produce a beat note of known frequency while a standard signal is applied to the receiver. For example, the bfo may be adjusted for a zero beat. If the bfo is left untouched, an unknown signal can now be measured by tuning the receiver until zero-beat conditions are obtained. The setting of the calibrated dial then gives the unknown frequency. When a nearby transmitter is being checked, the antenna of the receiver is disconnected. If the signal still blocks the receiver, the power amplifier of the transmitter should be turned off.

c. WAVEMETER METHOD.—An absorption-type wavemeter consists of an indicating device and an inductance and capacitance, either or both of which may be variable. A reaction-type wavemeter is essentially the same except that the indicating device is not present. Both of these frequency-measuring equipments have been discussed in paragraph 2-7.*c.*(1). The scales may be calibrated directly in frequency or may be used with a calibration chart or table. When tuned to the frequency of the transmitter and loosely coupled to the tank coil, a wavemeter will absorb a small amount of energy. The presence of this energy can be indicated in several ways. When a flashlight lamp or sensitive meter is used, resonance is indicated by maximum brilliance of the lamp or maximum deflection of the meter. As a rule, the capacitor is the variable element, and the band of frequencies covered by the instrument is determined by the coil in use. Typical circuits of absorption and reaction wavemeters are shown in section 2, figures 2-37 and 2-38. Generally speaking, above 200 mc special low-capacitance circuits, such as butterfly resonators, cavity resonators, or transmission lines are used. If improved sensitivity is desired, the lamp may be replaced by an electronic voltmeter or a crystal detector and d-c milliammeter.

Occasionally, a measurement is possible even when the power available from the circuit under test is not sufficient to actuate the indicator of the wavemeter. It is possible in the case of circuits that incorporate a grid or plate current meter to utilize the change in indication given by these meters when the wavemeter is tuned through resonance. The coupling should be loose so that the mutual inductance between the tank circuit and the wavemeter does not appreciably change the frequency of oscillation.

A well-designed wavemeter provides accuracies of 0.25 to 2.0 percent. Although not suitable for precise measurement, the absorption (and reaction) wavemeter is nevertheless an extremely useful general purpose instrument. For example, it is valuable whenever the detection of r-f energy in unwanted places is required, and whenever an approximate measurement of frequency is desired. One instance is the measurement of parasitic oscillations during the neutralization of an amplifier. Other uses are checking the fundamental frequency of an oscillating circuit, determining the amplitude and order of harmonic frequencies, and providing a relative measure of field strength.

d. HETERODYNE METER METHOD.—Frequency measurements of greater accuracy are possible with heterodyne frequency meters. To be most effective, such a meter must incorporate a small, fully shielded oscillator that covers the desired frequency range without the use of plug-in coils or switches. The tuning element of the oscillator is usually equipped with a vernier type dial to permit an accurate setting. In some cases the divisions of the dial may be engraved directly in terms of frequency, but more often a calibration book or chart is used with the instrument.

An electron-coupled oscillator is well suited for heterodyne meters. By using a voltage stabilized power supply and correctly proportioning the plate and screen voltages of the oscillator, it is possible to obtain extremely stable operation. Adequate power can be obtained from the plate circuit without impairing this stability. Another desirable property of the plate-circuit output is the presence of strong harmonics. More elaborate heterodyne meters also include a crystal-controlled oscillator which is used to check the accuracy of multiple

points on the calibrated dial. Calibration checks ensure accurate measurements. When the frequencies of the beating signals are exactly alike, the difference frequency is zero. Under this condition a null would be indicated by a signal-indicating device; for example, no tone would be audible in a head set. A heterodyne frequency meter utilizes this principle by beating the unknown signal against the output of its calibrated internal oscillator. Many heterodyne meters also include an antenna for picking up a radiated signal. Assuming that the instrument is placed near enough to the source of the frequency to be measured, this provision eliminates the need for a direct connection between the instrument and the source. The calibrated oscillator is then tuned for a zero-beat condition. When the zero beat is obtained, the unknown frequency is either the same as that of the calibrated oscillator or, as explained in the text to follow, it is a harmonic of the oscillator frequency. With the aid of the calibration chart, the dial reading of the frequency meter indicates the frequency under measurement. Another procedure is to radiate the oscillator signal by means of the antenna and to beat it against the unknown signal in an external receiver.

When frequencies greater than the upper limit of the variable oscillator must be measured, it is customary to beat harmonics of the oscillator against the unknown signal. The procedure is to turn the dial from the high end of the band, and note where the first two strong beats occur. The difference of the frequencies corresponding to the settings for zero beat then should be divided into the higher frequency. An integer will be obtained from this division and it should be multiplied by the lower frequency. This gives the unknown frequency.

As an illustration, suppose that the range of the heterodyne meter used lies between 100 and 200 kc. The first two strong beats, from the low end of the dial, produced by a signal higher than 200 kc in frequency occur at dial settings corresponding to 162.5 kc and 130 kc. Subtraction gives a difference of 32.5 kc. Division of this number into 162.5 kc produces 5. This means that the unknown frequency is the fifth harmonic of 130 kc, and is therefore equal to 650 kc.

A disadvantage of the previously described method is the uncertainty that sometimes arises when harmonics of the unknown signal combine with the internal signal to produce exceptionally prominent beats. Although such beats usually are not pronounced enough to be misleading, the foregoing procedure must be modified to include a wavemeter or some other means of approximating the unknown frequency whenever confusion is possible. Knowledge of the approximate frequency then ensures an exact measurement without the danger of error.

For example, suppose that the second harmonic of the 650-kc signal assumed in the preceding illustration can produce beats as strong as those arising from the fundamental. In this event, a zero beat will be obtained at a dial setting of 144.5 kc, since the ninth harmonic of this frequency equals 1300 kc. Naturally, if the beat occurring at the 144.5-kc setting were used instead of the one at 130 kc, the subsequent calculation would result in an answer of 1300 kc. By knowing the approximate frequency in advance, however, it would still be possible to make a true measurement. Under this circumstance, 1300 would be divided by two, giving 650 kc as before.

When an exceptionally high degree of accuracy is desired (for example, the recalibration of a frequency meter), a frequency standard supplemented by a multivibrator is employed to provide equally spaced harmonic points. Unless the unknown frequency coincides exactly with one of these harmonics, it is necessary to evaluate the frequency by an interpolation procedure. One excellent method utilizes a calibrated audio oscillator. As shown in figure 3-2, the output of a standard 100-kc generator is supplied to a 10-kc multivibrator. The harmonics applied to the heterodyning device, preferably a receiver, are therefore 10-kc apart. A signal furnished to the receiver beats against the harmonics to produce many new frequencies, the lowest of which is not higher than 5000 kc. This fact can be verified by referring to figure 3-3. The standard frequency, f_s, is 100 kc; a standard harmonic is represented by f_h, and the next harmonic by f_{h+1}. Similarly, the unknown frequency is designated by f_x and the nearest multivibrator harmonics by f_1 and f_2. When the beat signals are supplied to the calibrated audio oscillator, as shown in figure 3-2, the

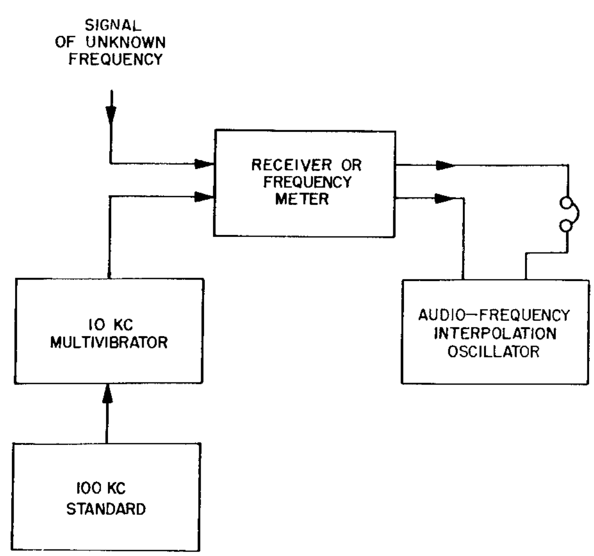


Figure 3-2. Test Setup for Audio-Frequency Interpolation

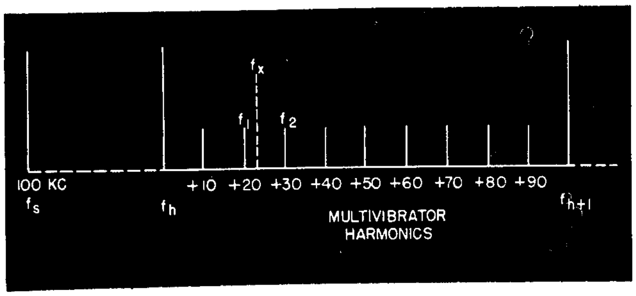


Figure 3-3. Spectral Relationship of Harmonic Frequencies and the Signal Under Test

oscillator should be adjusted for a zero beat with the lowest-frequency beat signal. In order to attenuate a higher beat note attributable to the next closest harmonic, which is f_2 according to figure 3-3, the receiver should be tuned halfway between f_1 and f_x so that the adjacent channel selectivity discriminates against f_2. The reading of the audio oscillator dial either is added to the frequency of the next lower harmonic, f_1, or subtracted from f_2, the next higher frequency. To decide whether to add or subtract, it is necessary to know the signal under test to within 5 kc of the nearest multivibrator harmonic. In the situation portrayed by figure 3-3, the reading is added to f_1.

The foregoing procedure is especially valuable as a means of recalibrating a heterodyne frequency meter. There are several advantages. One is the unlimited number of calibration points that are available. A second advantage is the utility made of only one frequency standard. Note in particular that frequencies less than that of the standard can also be checked. A third advantage of this method is its high degree of accuracy. Harmonic, or subharmonic points provide an accuracy equal to that of the standard, assuming the multivibrator to be well-designed, while the accuracy of other points is the same as that of the interpolation oscillator. If there is good adjacent channel selectivity in the receiver, only the harmonic nearest to the setting of the frequency meter will be appreciable in the output furnished to the oscillator. This tends to reduce uncertainty. When the receiver is employed, therefore, the unknown signal is delivered from the frequency meter being calibrated (refer to figure 3-2). If the receiver is eliminated, the output of the multivibrator is fed to the frequency meter, which applies the necessary beat note to the interpolation oscillator.

It is possible, of course, to apply the standard signal directly to the heterodyne frequency meter. This method is satisfactory only when the standard frequency is so low that a sufficient number of harmonics for calibration purposes is present in the band covered by the meter.

Interpolation is still possible when an audio oscillator is not available. Provided the receiver has a calibrated dial and less accuracy is acceptable,

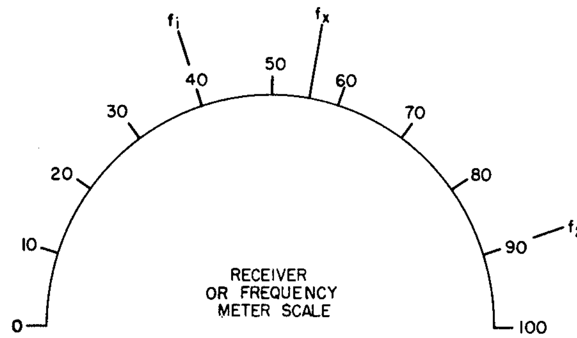


Figure 3-4. Linear Calibrated Scale, Showing Settings for Harmonic Frequencies, and the Signal Under Test

the interpolation may be performed arithmetically. As shown in figure 3-4, the dial readings for f_1, f_x, and f_2 should be noted. Since f_1 and f_2 are known exactly, the frequency under test, f_x, can be evaluated from the following relationship:

$$f_x = f_1 + \frac{(S_x - S_1)\ (f_2 - f_1)}{(S_2 - S_1)}$$

where: S_1 = dial setting for f_1
S_2 = dial setting for f_2
S_x = dial setting for f_x

The reading of the calibrated scale must be a linear function of frequency. This does not mean that there necessarily must be equal spacing between successive markers on the scale, although an evenly calibrated dial is desirable. There are a number of possible arrangements for obtaining a reading. Figure 3-5 shows a method using a frequency meter. The internal oscillator is first set

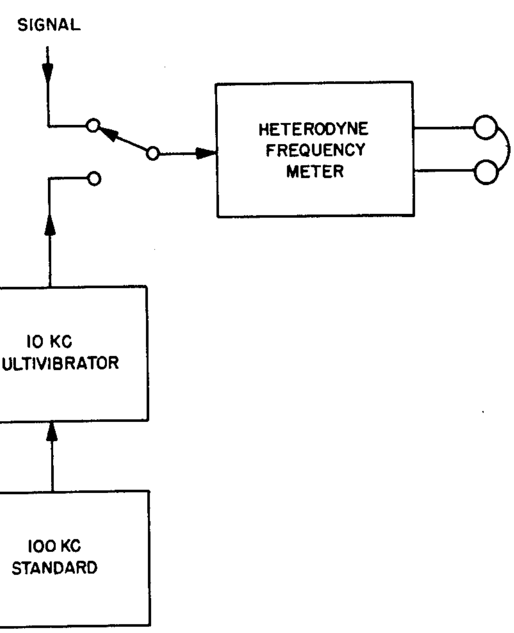


Figure 3-5. Test Setup for Arithmetical Interpolation

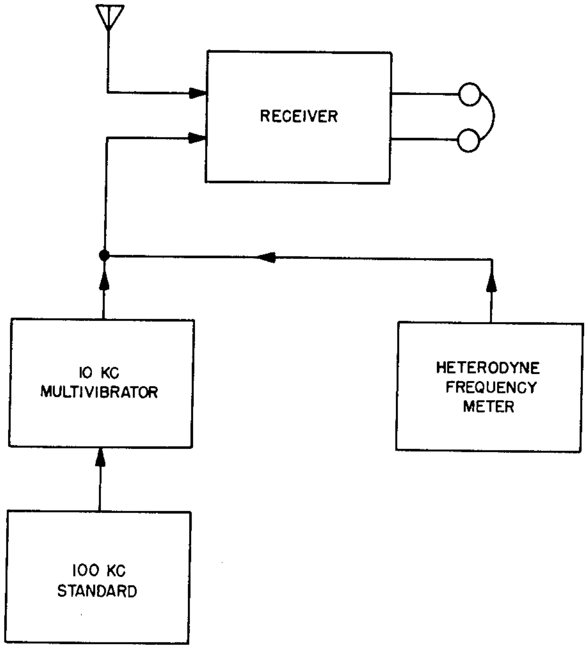


Figure 3-6. Test Setup for Measuring Frequency of Received Signal

for zero beat against the signal under test and the dial reading is noted. Then the output of the standard generator, or of the multivibrator, if used, is applied to the frequency meter. The dial reading for the two nearest harmonics is now obtained, and the computation described in the preceding paragraph is performed. A receiver with an internal beat frequency oscillator can be substituted for the frequency meter. When the frequency of an r-f transmission is to be measured and the receiver has no bfo, the setup shown in figure 3-6 is satisfactory. Here the receiver is tuned to the station, and the oscillator of the meter is adjusted to produce zero beat in the headphones. The dial reading of the meter is recorded. Without changing the setting of the receiver, it should be possible to zero beat the frequency meter against the two nearest multivibrator harmonics. After noting the readings of the frequency-meter dial, it is possible to interpolate the received frequency.

(1) ZERO-BEAT INDICATOR SENSITIVITY.—Precision testing based on the heterodyne principle necessitates the use of sensitive zero-beat indicators. Headphones may be acceptable to obtain an approximate indication of zero beat, but for greater accuracy visual methods of indication are desirable.

When exceptional sensitivity is required, a cathode-ray oscilloscope may be used. The sensitivity of the device increases with the amount of amplification preceding the cathode-ray tube. No vertical deflection occurs at the zero-beat condition. An effective indicator suitable for incorporation within a frequency meter utilizes an electron-ray indicator tube. The sensitivity of this simple device is excellent. Other visual type indicators are electronic voltmeters, rectifier-type a-f voltmeters, and neon lamps.

e. FREQUENCY COMPARATOR METHOD.—In recent years the simple heterodyne meters described previously have been refined into highly elaborate test equipments called frequency comparators. The heart of such an instrument is the standard frequency generator, usually a 100-kc crystal-controlled oscillator. The precise operation of this oscillator determines the accuracy of this instrument. Consequently, means for checking the frequency against the transmissions of radio station WWV are included. Refer to paragraph 2-7.*a.* for information on the operation and schedules of radio station WWV and WWVH.

A frequency comparator is shown in block diagram form in figure 3-7. Sometimes a duplicate frequency standard is provided so that it can be substituted automatically if the oscillator in use should fail. The standard signal is fed to a series of four "locked-in" oscillators, as shown in the figure. These oscillators divide the standard frequency into submultiples of tenths and also isolate the frequency standards from other circuits. Frequency-dividing multivibrators can be used in place of the locked-in oscillators, although the precision of the latter is somewhat superior. The output of any oscillator can be selected as excitation for a harmonic generating stage, but as a rule the output of the 10-kc locked-in oscillator is utilized. If the frequency of a transmission is to be measured, the output of the harmonic generator is supplied to the appropriate receiver. The output of the receiver then contains the difference-frequency components obtained from the signal under test, and the two nearest harmonics of 10 kc. It is also possible to include a separate mixer in order to extend the range of the comparator to low frequencies as shown in figure 3-7. The difference-frequency signals are applied to the interpolation oscillator, which is adjusted for zero beat. Reference to the dial of the receiver is the usual way of deciding which harmonic is closest in freqency to the signal under test. In the event of any uncertainty, the display of the panoramic adapter can be consulted. In this display, the various signals appear as vertical pips, resulting in a resemblance to figure 3-3. Hence, the adapter indicates which harmonic is closest in frequency to the incoming signal. A 1-kc synchronometer is included in order to simplify checks of the standard frequency. This device, driven by a 1000-cycle synchronous motor, is capable of accurately counting the number of cycles produced by the standard oscillator during a designated time interval. Readings are facilitated by a large, illuminated 24-hour dial with a long sweep hand. There is also a microdial contactor that operates once each second. Calibrated in hundredths of a second, it makes

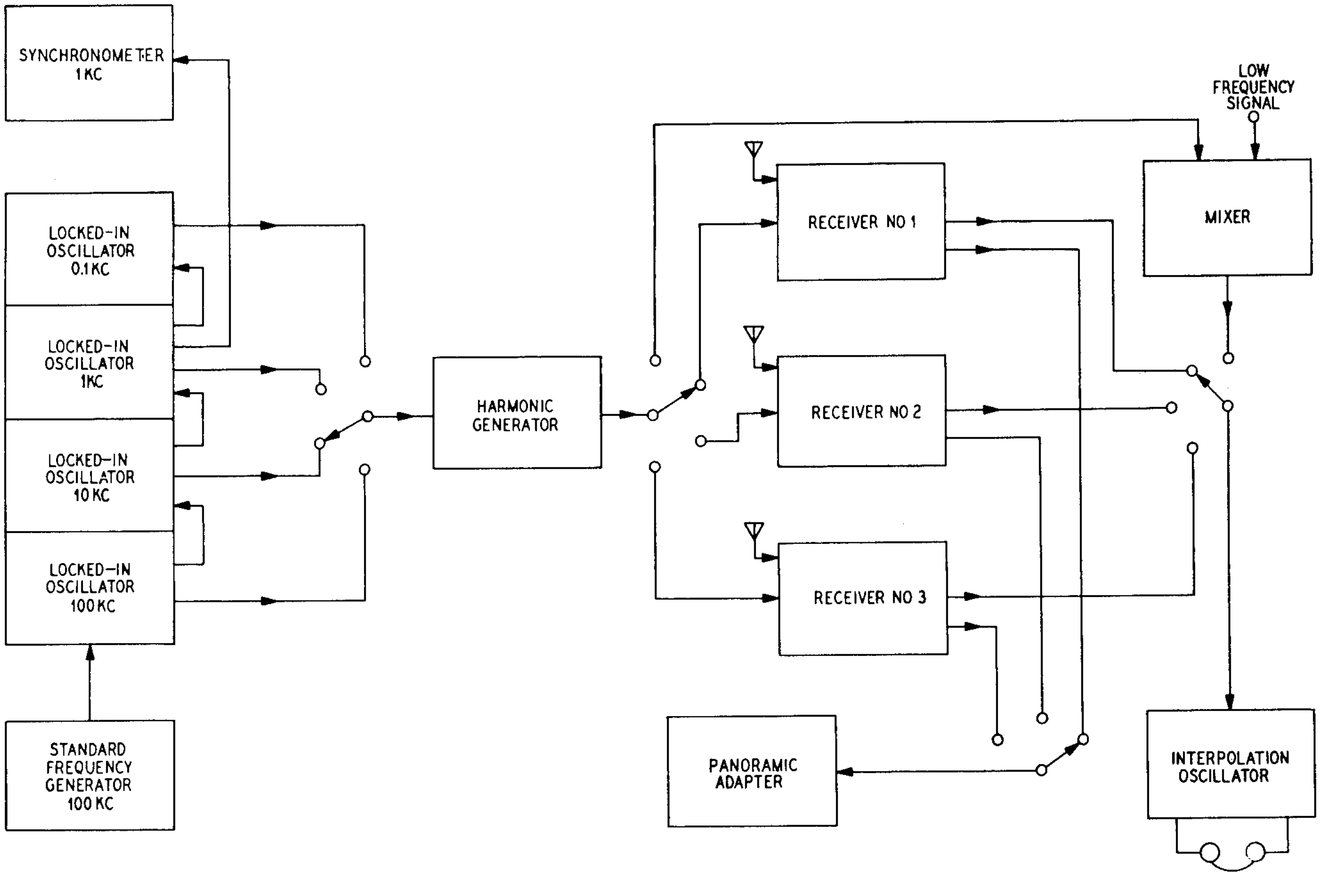


Figure 3-7. Block Diagram of Frequency Comparator

comparisons with time signals accurate to one part in ten million over a 24-hour interval. The usual procedure is to compare the synchronometer with the time signals transmitted by Station WWV. This shows how accurately the standard frequency has been maintained during the period between transmissions. Phasing of the microdial mechanism is accomplished by means of a panel control. A 60-cycle motor is provided in order to start the 1000-cycle synchronous motor when a push button on the panel is operated.

f. FREQUENCY MONITOR METHOD.—As stated earlier in the text, Government regulations specify certain tolerances for the frequency of transmissions. The heterodyne principle is also employed in devices called frequency monitors to indicate the amount of deviation from an assigned value. Generally, a deviation within 30 cps of the nominal frequency can be read directly from a calibrated meter, and in some instruments even greater deviations are indicated.

The internal oscillator of the monitor must be independent of the frequency control of the transmitter and must be accurate to within five parts in a million. It is customary for the frequency of this oscillator to be 1000 cps greater or less than that of the transmitter. When no deviation exists, a difference frequency of exactly 1000 cps will be produced. This signal is fed to a frequency meter designed so that half-scale deflection corresponds to a 1000-cps signal. When the transmitter deviates from its assigned frequency, it is evident that the difference frequency will be either a little more or less than 1000 cps. If the frequency of the monitor oscillator is below the frequency of transmission, an increase in the latter frequency results in a beat note that is greater than 1000 cps. If the frequency of the monitor oscillator is greater than the frequency of transmission, an increase in the latter frequency results in a beat note that is less than 1000 cps. In either case, the frequency meter of the monitor should correctly indicate the amount of positive deviation. Similar provisions hold in the event of a negative frequency deviation.

g. HIGH-FREQUENCY MEASUREMENT TECHNIQUES.—In the discussion of transmission lines in Section 2 (paragraph 2-10) it was stated that standing waves exist on a line not terminated in its characteristic impedance. At frequencies in the VHF region or higher, this phenomenon can be utilized to measure wavelength by direct measurement. Strictly speaking, the method

is applicable to lower frequencies as well, but the long wavelengths involved make the techinque impractical.

(1) LECHER-WIRE METHOD.—In this method standing waves are established on an open two-wire parallel transmission line. Since the distance between successive peaks (or nodes) is equal to a half wavelength, a direct measurement of this distance will enable the frequency to be determined. This principle was utilized by E. Lecher as early as 1890, and for this reason open parallel lines are known as Lecher wires.

There are a number of ways in which the length of a standing wave can be ascertained. In Section 2, figure 2-43 illustrates a procedure which determines either current peaks or current nodes in the transmission line. The length of the Lecher wire is not important provided it is at least a wavelength long. There should be loose coupling between the line and the source of current, so that the normal frequency of the source is unchanged during the measurement. Since standing waves are pronounced when the far end of a line is open- or short-circuited, either of these possible terminations may be used. By sliding a current-indicating device (preferably a thermocouple ammeter) along the Lecher-wire frame, points of maximum current (loops) will be disclosed by maximum deflection of the instrument. Points of minimum current (nodes) will be indicated by minimum deflection. The distance between successive maxima or minima is always equal to a half wavelength. This distance can be readily measured with a suitably calibrated scale. If the measurement is in meters, the frequency in megacycles will be $f = 150/\text{distance in meters}$. Similarly, a measurement in inches is related to frequency by: $f = 5905.5/\text{distance in inches}$. A voltage indicator, such as the neon lamp shown in figure 3-8, can also be used to make a measurement.

There are a number of precautions to observe. The measurement itself must be made with extreme care, as the accuracy of the result is limited

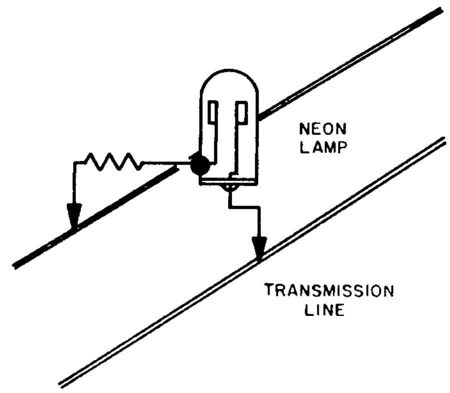


Figure 3-8. Neon Lamp Indicator

by the physical measurement. The looser the coupling, the sharper will be the indications of maxima or minima. It is desirable for air to be the dielectric separating the conductors of the line. These conductors should be made of copper tubing or of wires stretched tautly between convenient supports. Satisfactory spacing between the conductors lies approximately from one to one-and-a-half inches. The contacts of the meter should be maintained at right angles to the line. A test system can be employed more conveniently and accurately if built solidly and in a permanent fashion. It has been found from experience that somewhat greater accuracy is possible by measuring the distance between nodes rather than peaks. If the foregoing precautions are taken, an accuracy as high as 0.1 percent is possible.

(2) ALTERNATE METHOD.—The resonant properties of the short-circuited transmission line can be utilized somewhat differently to measure wavelength as shown in figure 3-9. Here the current indications are found by moving a shorting bar, which is simply a metal strip or knife edge, along the length of the Lecher wire. Once again, the coupling between the source and the line must be as loose as possible. Also, coupled loosely to the

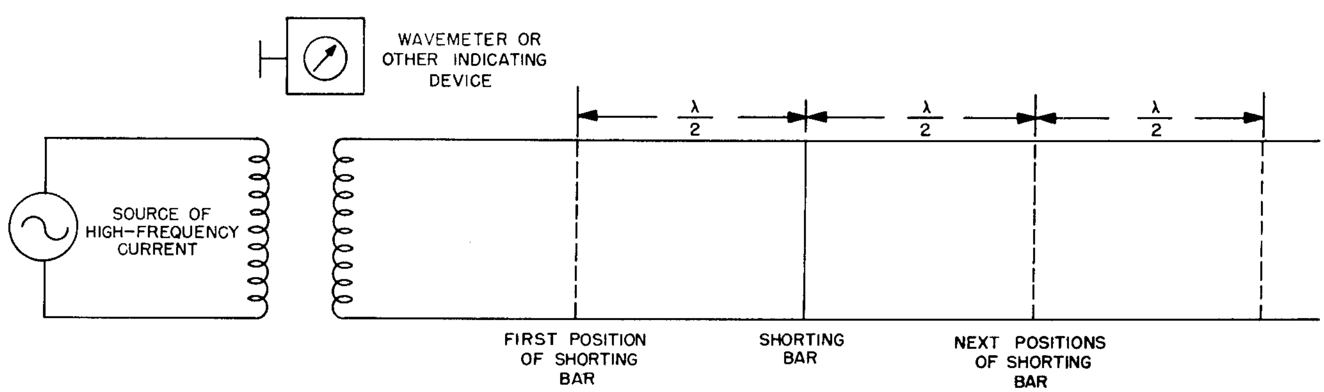


Figure 3-9. Test Setup for Lecher Wires—Shorting-Bar Method

source is some convenient indicating device, such as a wavemeter or even a flashlight lamp connected to a loop of wire. As the shorting bar is moved toward the far end of the line, it will reach a resonance point at which a pronounced dip in the meter indication or glow of the lamp will take place. With the shorting bar in such a position, the line is tuned to the frequency of the source and so absorbs maximum energy from it. At a half wavelength beyond the first resonant point, the line will exhibit the same characteristics. The distance between these points must be measured carefully, as explained previously.

The frequency of a superregenerative receiver can be accurately determined by this alternate method, provided the coupling between the receiver and the line is extremely loose. At the desired setting of the receiver, an adjustment should be made so that the characteristic hiss is barely heard. Then as the bar is moved along the line, a point will be reached where the receiver goes out of oscillation. The distance between two such points is equal to half a wavelength.

3-5. TRANSMITTER TESTING—POWER MEASUREMENTS.

Electrical power delivered to a load at any instant is equal to the product of the voltage across the load and the current passing through it, or P = EI. Under stable d-c conditions, this product is also equal to the average power consumed. In a-c circuits, on the other hand, the presence of either inductive or capacitive reactance means that the apparent power, EI, where both voltage and current are r-m-s values, must be multiplied by a number called the power factor to obtain the true power. Briefly, this is necessary because pure inductors and capacitors store energy furnished by the line, and, during a later portion of the cycle, restore such energy to the line. If purely reactive circuits were possible, therefore, none of the power would be dissipated. Naturally, resistance is an unavoidable component of any reactance, so from a strict standpoint nondissipative networks are not attainable. In practical a-c circuits, the power dissipated is equal to the apparent power multiplied by the cosine of the phase angle between the voltage and current. Refer to paragraph 2-6.*a*.

Calibrated voltmeters and ammeters are used as a direct approach to power measurements in d-c circuits. Usually, approximate indications of power are satisfactory in electronic circuit work, so that neither the expense nor the inconvenience of two separate meters is justified. A typical instance is that of determining whether the power rating of a resistor is adequate. It is generally acceptable to measure the voltage across the resistor and then to calculate the power by the basic equation $P = E^2/R$. For current rather than voltage measurement, the power is equal to I^2R. If the designated resistance of the part is not sufficiently reliable, it may be measured approximately with an ohmmeter. Conceivably, an extremely accurate measurement may be required, in which case a determination by means of a Wheatstone bridge can be made. Similarly it may be necessary to determine the a-c power dissipated by a resistive load, either at audio or radio frequencies. The same method is reliable, provided the resistance of the device is known at the frequency in question.

a. AUDIO-FREQUENCY POWER MEASUREMENT.—In testing operations which require the repeated measurement of audio-frequency power it is customary to employ one of several commercially available power meters. The usual components of such instruments are a variable-ratio transformer, a constant-resistance multiplier, and a voltmeter functioning with a copper-oxide rectifier. Use of the transformer, which is compensated by various resistances, enables the effective load imposed on the output stage to be varied over a number of steps. The constant-resistance multiplier acts as a range multiplier for the voltmeter while presenting a constant resistance to the secondary of the transformer. The indicating instrument is calibrated directly in watts.

When reactive components of the dissipative impedance introduce a phase angle, the foregoing methods are no longer applicable. A device proportional to the power factor as well as to the apparent power must be used instead. Accordingly, a large number of instruments, called wattmeters, have been successfully developed for low-frequency power measurements.

(1) ELECTRONIC WATTMETER METHOD.—The method about to be described utilizes an electronic wattmeter circuit based on the balanced modulator discussed previously. As shown in figure 3-10, a source of a-c power is connected to the load through the series resistors, R2. These two resistors of equal value are made small

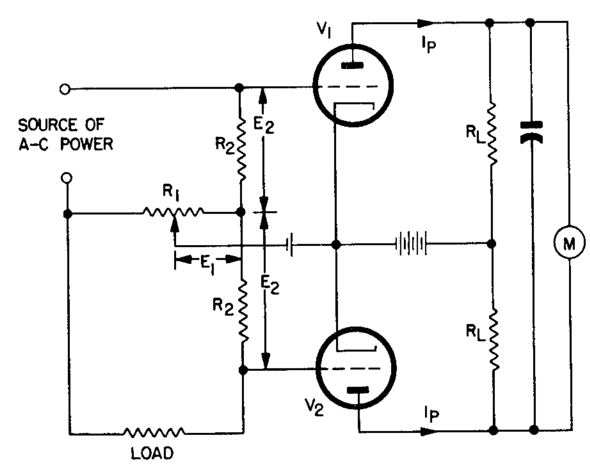


Figure 3-10. Electronic Wattmeter Circuit

enough to keep the drop across them from reducing the load voltage appreciably. In contrast resistor R1 is made very large so that its power consumption is negligible. These restrictions make the voltage across R1 equal to the load voltage, and the voltage across either series resistor proportional to the load current. Inspection of the figure shows that the voltage across the grid circuit of the upper tube, is E1 plus E2, while the net voltage applied to the lower tube is E1 minus E2. In the output circuit, the resistances in the plate circuits of the tubes are equal. This provision makes the difference of potential between the plates proportional to the difference in the output currents of the tubes. The average value of the difference is indicated by the d-c meter connected to the plates. For the circuit to function as a wattmeter, the tubes must be operated over the nonlinear portion of their characteristic curve. This operation causes the difference current to consist of a number of components. The components proportional to either E1 or E2 make no contribution to the reading, as the average value of a sine wave is zero. (E1 and E2 are r-m-s values of sine-wave voltages.) The only other appreciable component is the one proportional to the product of E1 and E2, that is, proportional to the product of the load voltage and current. The average value of such a component is proportional to the product of E1 and E2 multiplied by the cosine of their phase difference. Consequently, the meter reading is proportional to the power consumed by the load, and the scale is therefore calibrated in watts. Nonlinearity of the scale may be minimized by using inputs of low value to the tubes.

(2) FREQUENCY LIMITATIONS.—The preceding methods for the direct measurement of a-c power are satisfactory only when the frequency is fairly low. As the frequency increases, a number of serious difficulties are experienced. The most injurious effect is that of stray capacitance and inductance. Up to a point, the physical size of r-f components in the older types of power-measuring equipment could be scaled down, thus extending their upper frequency limit. Nevertheless, the benefit of such procedure is so restricted that development of entirely new methods has been necessary. Other conditions to be overcome are skin-effect resistance, the problem of determining the power factor at high frequencies, and the difficulties encountered in measuring large magnitudes of r-f power.

Because of the widely known fact that even a substantial reduction of power does not significantly decrease operating range, the precise measurement of r-f power may appear to be unnecessary. This is a false conclusion. One reason is that a change in the power output may result from altered operating conditions that are capable of causing equipment breakdown unless remedied.

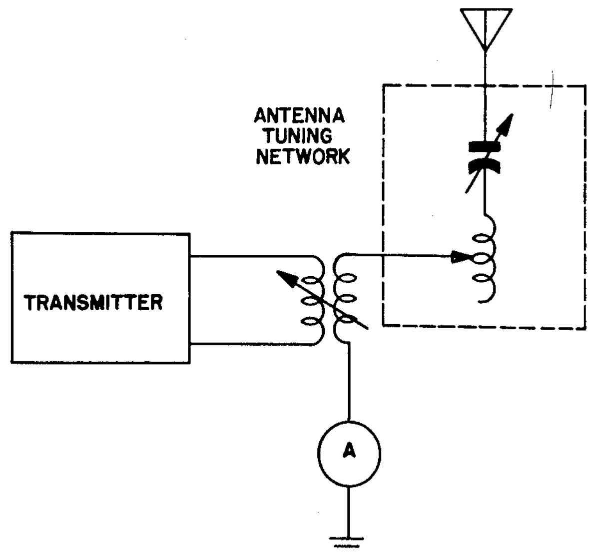


Figure 3-11. Circuit for Testing Antenna Input Power

In addition, power measurements are often the surest way of determining whether the over-all performance of a transmitter is normal and in general consistent with the specifications of the manufacturer. Tests should therefore be made periodically, either with the same equipment or with different instruments of equal accuracy. If this practice is observed, a change in the indication will reliably signify trouble rather than a discrepancy between the instruments.

b. DIRECT R-F POWER MEASUREMENT.—At all frequencies except UHF and SHF, it is usually possible to measure the effects of power directly; for example, the method of measuring the load voltage and current in d-c applications. In fact, modifications of this basic procedure utilizing the thermocouple ammeter are virtually standard practice at the lower radio frequencies, and have been employed for frequencies as high as 60 mc. This method relies on two principles. One is the unity power factor of a resonant antenna circuit. The second is the power relationship $P = I^2R$, where P is the power delivered by the equipment, I is the r-f current through the antenna, and R is the effective resistance of the antenna.

Thermocouple ammeters are well suited for the measurement of r-f current, and are therefore used extensively in circuit arrangements similar to that of figure 3-11. Usually, the meter is calibrated to indicate the square of the current. This part of the direct procedure for measuring r-f power is standard practice, but to be useful it must be preceded by an accurate determination of the effective antenna resistance.

(1) ANTENNA RESISTANCE MEASUREMENT TECHNIQUES.—Three basic techniques

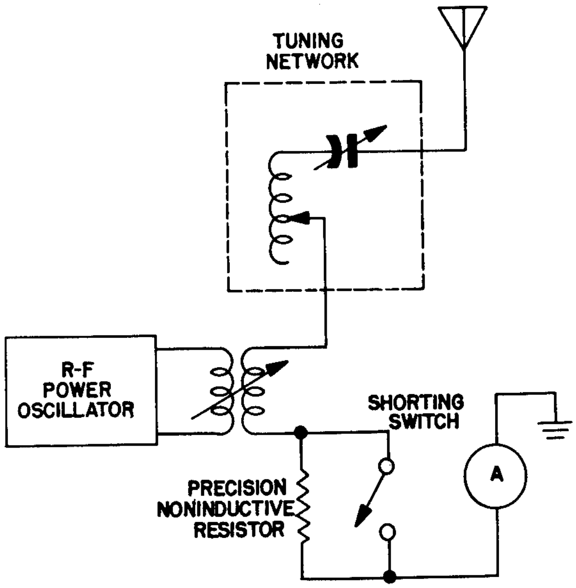


Figure 3-12. Test Setup for Variation Method of Measuring Antenna Resistance

devised for the measurement of antenna resistance are called the variation, the substitution, and the bridge methods. The necessary apparatus for the variation and substitution methods are as follows: an r-f generator that covers the desired frequency range with an output power rating of 50 watts approximately; a wavemeter or heterodyne frequency meter covering the desired frequency range, and accurate to within 0.25 percent (required by the FCC); a thermocouple ammeter or other type acceptable for the frequency range under test, with an accuracy of about 2.0 percent; a tuning capacitor and an inductor, with values suitable for the frequency range being measured; and a decade resistor or suitable noninductive resistor, accurate to within approximately 1.0 percent. The requirements of the bridge method will be stated later. Regardless of the method chosen, a series of measurements at different frequencies centered on the stipulated transmission frequency should be made if a high order of accuracy is desired. From the data collected, a graph of resistance versus frequency should be plotted, with the frequency appearing on the X axis. If the transmission is in the broadcast band, 10 to 12 measurements extending over a band 40 to 60 kc wide are recommended. The resistance indicated at the assigned frequency specifies the antenna resistance to be used in the power calculation. It is considered advisable to restrict the maximum dissipation of power in the antenna during the test to 10 percent of the power obtainable from the r-f generator in use. Although a broadcast transmitter is not ordinarily employed for testing purposes, it can be, provided the output of an early, low-power stage is used.

(2) BASIC VARIATION METHOD.—In this method of measuring antenna resistance, a standard or known value of noninductive resistance is placed in series with the antenna and ground, as shown in figure 3-12. A wavemeter should be used to measure the frequency of the signal applied to the antenna circuit. By means of the tuning inductor and capacitor, it is possible to vary the resonant frequency above and below the fundamental frequency of the antenna and thus secure sufficient data for a graph. The tuning inductor is often omitted.

(*a*) TEST PROCEDURE.—The procedure for measuring antenna resistance based on figure 3-12 is described in the steps below.

1. The first antenna resistance measurement is taken at the natural frequency of the antenna system. First, connect the antenna to the ground or counterpoise through the coupling coil in which the signal is introduced. Make certain that the antenna circuit is energized only through the coupling coil. This precaution requires that the oscillator be shielded carefully and stray capacitances between the coupling link and other points in the antenna circuit be reduced.

2. Tune the r-f oscillator. There should be a noticeable dip in the grid-circuit milliammeter of the driver stage. This dip will occur at the resonant frequency of the antenna system. At the instant of the lowest grid-current reading, the deflection of the antenna milliammeter should be maximum. Be sure that the indication of the grid milliammeter changes gradually as resonance is approached in either direction. An abrupt dip followed by a quick return to the original indication means that too much coupling exists between the driver and the antenna circuit. In this event, it is necessary to loosen the coupling until reaction between the two circuits is negligible. When accuracy is desired, a powerful driver should be used and located several feet from the antenna.

3. Record the current flowing in the antenna circuit at the resonant frequency. After the known resistance has been connected in the antenna circuit, read the antenna current again. Make certain that the oscillator is not disturbed once the first antenna-current reading has been taken. The following formula gives the antenna resistance in ohms:

$$R_a = \left(\frac{I_s}{I_a - I_s} \right) R_s$$

where R_a is the value of antenna resistance, I_s is the current measured when the standard resistance is in the circuit, I_a is the current measured when the standard resistance is out of the circuit, and R_s is the value of standard resistance. The foregoing method evaluates the antenna resistance at the fundamental frequency of the antenna.

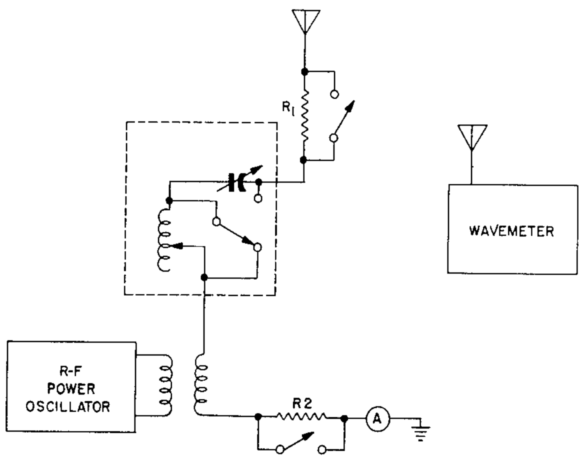


Figure 3-13. Test Setup for Two-Resistor Method of Measuring Antenna Resistance

4. It is now necessary to determine the resistance of the antenna at the frequency of transmission. Therefore, connect the tuning network, which should be shielded in order to eliminate any stray coupling paths. Refer to the network enclosed by the dotted line in figure 3-12. In accordance with the previous step, tune the circuit to resonance at the frequency of transmission and read the antenna current once again. The standard resistor should remain in the circuit. Repeat this procedure for a number of additional frequencies, and plot a resistance versus frequency graph. The value of antenna resistance at the transmitting frequency obtained from the graph should agree with the measured value within reasonable limits.

(3) TWO-RESISTOR VARIATION METHOD.—The circuit shown in figure 3-13 is often helpful in disclosing the existence of stray capacitive paths to ground. Although an L-C tuning network is shown, a calibrated capacitor ordinarily is used in this function alone. Note that in this circuit a standard resistor is present on the antenna side of the tuning network as well as on the shielded side.

(*a*) TEST PROCEDURE.—The procedure described in the following steps should be observed for each frequency at which a resistance measurement is made:

1. Short out both standard resistors, then adjust the tuning network of the antenna circuit to resonance. This is indicated by maximum antenna current. Then adjust the output of the oscillator for a convenient deflection of the meter. Once this adjustment is made, it must be left untouched throughout the remaining procedure. Record the antenna current with the standard resistors out of the circuit.

2. Insert a known value of resistance (R_1) into the circuit, and measure the antenna current again. Now compute the antenna resistance by means of the formula given in the discussion of the basic variation method.

3. Short out R_1 and insert a known value of R_2. With R_2 in the circuit, make another measurement of the antenna resistance. The two methods of determining antenna resistance will agree only if there is no appreciable stray capacitance between the measuring circuit and ground. Assuming that the shielding is satisfactory, residual capacitances are dependent upon the geometry of the surfaces presented by the various items of equipment. Naturally, the geometry of the setup is different for each physical arrangement of the components. In the event of contradictory results, therefore, it will be necessary to relocate the components and to repeat the tests. This procedure must be continued until there is a setup for which capacitive effects are small, as indicated by reasonable agreement between the two measurements. Of the two values, the resistance obtained by using R_1 is the more accurate, and it should be used to obtain the final measurement. Care is especially important when measuring the resistance of high-impedance antennas, particularly near a frequency corresponding to a half wavelength.

4. The reactance of the antenna at the test frequency is easily determined if such information is required. If a precision tuning capacitor alone is used in the tuning network, the reactance of the capacitor at the resonant setting ($X_c = \frac{1}{2}\pi fC$) is equal to the antenna reactance. If a tuning inductor is used as well, the net reactance of the tuning network is equal to the antenna reactance. These statements presume that it is safe to ignore reactance of the coupling coil and the standard resistors, and stray effects due to wiring.

(4) SUBSTITUTION METHOD.—As suggested by its name, the substitution method of measuring antenna resistance involves the replacement of the antenna by equivalent amounts of resistance and reactance, either inductive or capacitive, according to the property of the antenna. Figure 3-14 shows a circuit arrangement in which capacitance is used to help simulate the antenna. The substitution method is usually performed at the frequency to which the antenna circuit has been made resonant, and ordinarily this will be the operating frequency. If the frequency is already known, it is necessary only to place the switch in position 1 and to set the r-f oscillator at the resonant frequency by means of its calibration or preferably with the aid of the wavemeter. If the antenna system has not been made resonant to the operating frequency, it should be adjusted by means of its tuning elements before the resistance measurement is begun. This is accomplished by using the wavemeter to set the oscillator at the operating frequency, followed by an adjust-

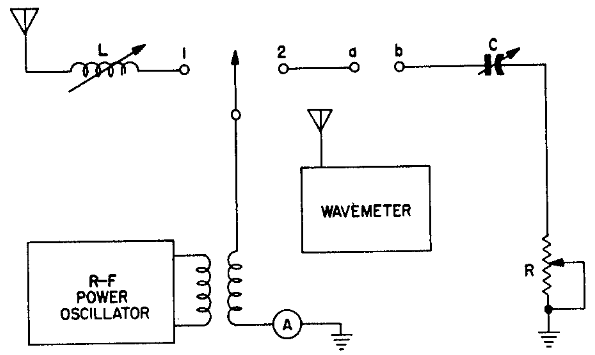


Figure 3-14. Test Setup for Substitution Method of Measuring Antenna Resistance

ment of the antenna tuning elements for maximum antenna current. As pointed out in the previous discussion, if the coupling between the two circuits is sufficiently loose, the grid current meter in the driver should indicate a gradual dip as the antenna circuit approaches resonance.

Certain pitfalls must be avoided for accurate determinations. Primarily, there must be no stray transfer of energy into the antenna circuit. In this regard, it is essential for the oscillator to be well-shielded, so that energy absorbed directly by the antenna is small compared to the energy induced in the coupling coil. If it is not possible for the oscillator to be shielded adequately, the antenna energizing current must be as high as the oscillator in use will permit. Even when shielding is satisfactory, a high antenna energizing current helps to improve accuracy. The r-f generator should therefore be capable of delivering substantial power, at least 50 watts in the M-F range.

(*a*) TEST PROCEDURE.—The procedure for determining antenna resistance by the substitution method is as follows:

1. With the switch in position 1, measure and record the antenna-circuit current. It is assumed that the oscillator has been set at the operating frequency by means of the wavemeter.

2. Place the switch in position 2, so that the antenna is disconnected. If an inductor, such as that indicated by L in figure 3-14, has been used to resonate the antenna to the operating frequency, the use of a resistor and a tuning capacitor is indicated, shown as R and C in the figure. On the other hand, if a capacitor has been used to tune the antenna, a precision inductor must be used with the resistor.

3. Connect the antenna tuning element to point a and point b as indicated in figure 3-14. Then tune capacitor C (or an inductor, if used) until resonance of the second circuit is indicated by maximum deflection of the milliammeter. Refer to the wavemeter in order to maintain a constant frequency. Vary the resistance of R until the meter reading is the same as the value recorded when the antenna was connected. Under this condition, the resistance of R is equal to the antenna resistance, and the reactance of the tuning capacitor is equal to the reactance of the antenna circuit at the resonant frequency. The tuning capacitor and resistor are often referred to as a dummy antenna, since they are also used in testing procedures when it is necessary to load transmitting equipment properly without allowing radiation of the signal.

4. Using the wavemeter, adjust the oscillator to various other frequencies, above and below resonance, and repeat the foregoing steps at each frequency.

(5) R-F BRIDGE METHOD.—The bridge method is perhaps the most rapid and accurate means of determining antenna impedance, if connections are made properly and adequate shielding is provided. Several r-f impedance bridges are available for this purpose, although the circuit shown in figure 3-15 is widely used. Regardless of the instrument selected, instruction manuals or other pertinent literature should be consulted. Although illustrative of the bridge method in general, the exact details of the following presentation apply only to an instrument incorporating the provisions of figure 3-15. In addition to the bridge, a well-shielded signal generator providing an output of 1 to 10 volts and a well-shielded receiver having a sensitivity between 1 to 10 microvolts are necessary. The receiver serves as an indicating device for the bridge, so that a dependable balance can be attained. In this application, the avc of the receiver must be disabled, and, if possible, a beat-frequency oscillator should be included so that an audio output will be heard even if an unmodulated r-f signal is used. The usual communications receiver satisfies these requirements.

The characteristics of a bridge type instrument based on the circuit shown in figure 3-15 will now be described. Capacitor C1 in the upper left arm of the bridge is attached to a calibrated dial which indicates the unknown resistance. Shunting C1 is another capacitor, C2, which is adjusted for initial balance when the terminals to which the unknown impedance is connected are shorted. These terminals will be referred to in the discussion as the "unknown" terminals. Inclusion of C2 enables the initial setting of C1 to be made zero, and its dial will therefore specify the unknown resistance directly in ohms. Adjustment of this dial during an actual impedance measurement is always in the increasing direction. Located in the lower right-hand arm is capacitor C3, which specifies the reactance of the unknown impedance. In the event that inductive reactance is being measured, C3 must be decreased in capacitance from its original setting, and the calibration of the dial is arranged to increase. Conversely, a measurement

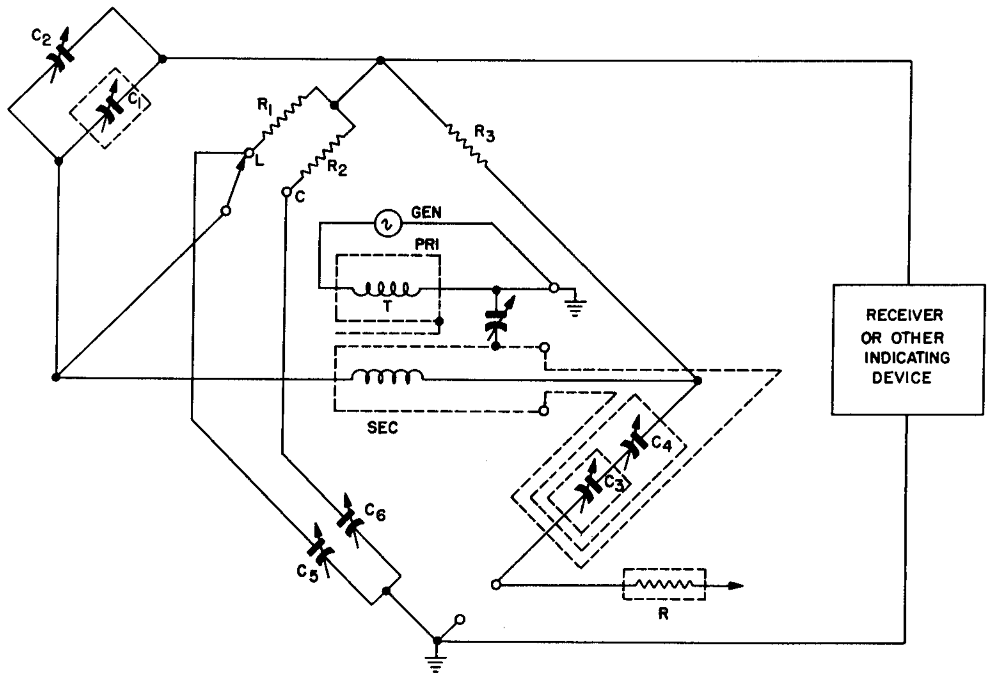


Figure 3-15. Circuit of Typical R-F Bridge

of capacitive reactance necessitates an increase in the capacitance of C3, resulting in a corresponding decrease in the dial setting. When an inductive reactance is to be measured, therefore, the switch in the upper left-hand arm is placed in the L position and the preliminary balance of the bridge is made with C3 set at zero. A second balance is made after the unknown impedance is connected. The dial setting divided by the frequency in megacycles then gives the inductive reactance in ohms. When a capacitive reactance is to be measured, the switch in the upper left-hand arm is operated from position L to C and C3 is set at 5000 ohms (maximum) during the preliminary bridge balance. To determine the unknown capacitive reactance, the final reading of the dial is subtracted from 5000 and divided by the frequency in megacycles. An example will be given later.

An important requirement of any r-f bridge is extensive shielding, as indicated by the broken-line enclosures of figure 3-15. Shielding protects the inherent balancing property of the bridge by preventing stray paths from affecting the bridge circuit. Of particular interest is the elaborate shielding of the special transformer, T, through which the generator output is applied to the bridge, an especially important consideration at balance.

An additional resistance, resistor R, must be connected in the unknown impedance arm, so that capacitor C1 can be set to zero during the preliminary balancing operation. Although it would be desirable to locate the resistor physically within the bridge, capacitive effects necessitate placing the resistor in the special test lead, usually near the end connected to the bridge. Frequently, both a long and short lead are provided, but the short one should be utilized whenever possible.

The equipment should be connected with considerable care, since measurements taken at radio frequencies are vastly more difficult than those taken at audio frequencies. One especially important practice is to make all ground connections at a single ground point with short one-inch copper strips. If the bridge is properly grounded, its balance will not be affected by touching the panel. It is necessary, of course, to use suitable connectors to connect the r-f generator and the receiver serving as the balance detector. If these equipments are grounded properly, touching their panels will not affect the balance of the bridge. In extreme situations it may be necessary to connect separate grounds from each piece of equipment to the bridge, and from the bridge to a ground. To check the shielding of the generator, remove the detector (receiver) cable from the panel jack of the bridge. If there is adequate shielding, the pickup of the receiver will be small. Finally, it should be possible to touch the shield connection of the cable against the ground terminal of the bridge without greatly increasing the output of the receiver. If the output of the receiver is considerable when disconnected from the bridge, coupling through the power line and poor shielding are possible causes.

(*a*) TEST PROCEDURE.—To illustrate the bridge method of antenna impedance measure-

ment further, an example will be considered. An antenna that is intended for operation at 840 kc must have its impedance determined. The procedure is presented in the following steps:

1. The antenna terminal is commonly mounted on a metal rack, which is frequently installed in a small house at the base of the antenna tower. A convenient point or terminal of the metal rack makes an excellent place at which to ground the measuring equipment. Choose this point as close to the antenna terminal as possible. Remember that the use of the shorter lead is recommended; therefore, locate the bridge near the antenna terminal. At first, connect the test lead to the ground point of the rack in order to short-circuit the terminals for the unknown impedance and to make possible the preliminary balance of the bridge. Since the lead will soon be shifted to the antenna terminals, improvise an arrangement that restricts its movement to a minimum. One possibility is to suspend the lead with a string.

2. An antenna in the lower M-F range is frequently less than a quarter wavelength long. In this event, its reactance would be capacitive. Consequently, the switch on the bridge panel should be placed in the C position. With the test lead still shorted to the metal rack (ground), set the resistance dial to zero and the reactance dial to 5000 (maximum). Attain the preliminary balance by adjusting C2 and C4. The signal generator should be set at 840 kc and the frequency checked by means of a wavemeter.

3. Connect the test lead to the antenna terminal and rebalance the bridge. The resistance of the antenna at 840 kc can now be read directly from the resistance dial.

4. To obtain the reactance of the antenna, subtract the reactance reading from 5000 and divide this difference by 0.84. For instance, a reading of 4897 gives a difference of 103. This figure is divided by 0.84 to produce 122.6 ohms.

5. Now make aditional measurements over a range of frequencies in order to secure more knowledge of the impedance properties of the antenna.

(6) R-F POWER METER APPLICATIONS.—When less accuracy in the measurement of r-f output power is acceptable, compact test equipments called r-f power meters are used to furnish direct readings of r-f power. The principle of the usual r-f power meter is not complicated. If the r-f power of a transmitter is low or moderate, it is possible to dissipate the full amount in a suitable resistance and utilize part of the resulting voltage drop to operate a meter calibrated to read in watts. In contrast to the comparative bulk of the equipment mentioned earlier, a power meter is compact and portable when designed for use with transmitting equipment having power ratings up to 500 watts. A typical instrument of this kind is generally most useful for frequencies ranging from 3 mc to 300 mc.

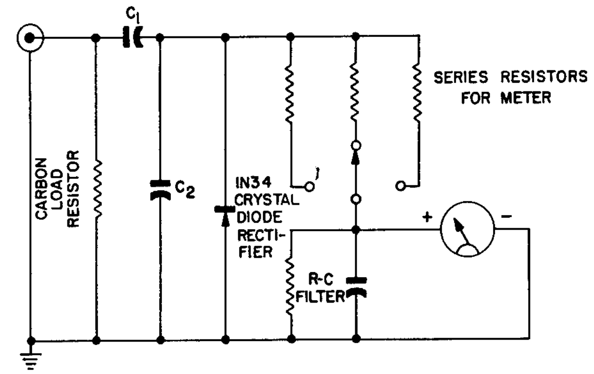


Figure 3-16. Circuit of Typical R-F Power Meter

Figure 3-16 shows a representative circuit of a typical r-f power meter. Note in particular the load resistor shunted directly across the output terminals. Unless this resistor is capable of dissipating the entire r-f energy delivered to it, the heat generated will open the resistor and possibly cause other damage to the test equipment. For low-power meters of the type shown in figure 3-16, carbon piles are often employed, that is, discs of carbon are mounted on a suitable rod in sufficient quantity to comprise a resistance. At the higher frequencies, the value of resistance must closely approximate the characteristic impedance of the transmission line used to couple the transmitting equipment to the antenna. When the trasmission line is properly terminated by the carbon pile, the standing-wave ratio on the line will be negligible, and the full power of the transmitter will be delivered to the r-f meter. The meter is also used at lower frequencies when the output impedance of the transmitter is substantially equal to the value of the loading resistor in the meter.

In the circuit of figure 3-16, capacitors C1 and C2 form a voltage divider. C1 is made small (about $5\mu\mu f$) in order to sustain a high percentage of the voltage developed across the loading resistor. It also maintains the capacitive reactance shunted across the load high, so that there is little effect on the standing-wave ratio. Only a relatively small voltage drop appears across C2, which has a value of about .25 μf. The crystal diode in parallel with C2 provides a direct path to ground when the polarity of the incoming signal is negative, causing the average voltage developed across C2 to be positive. This voltage produces deflection of the meter, which is calibrated to read directly in watts. According to the amount of power involved, a suitable resistance is switched in series with the meter movement. An r-f filter is shunted across the meter.

Low amounts of power can be applied continuously to the meter, while higher amounts can be

applied only long enough to obtain a reading. The upper frequency limit of the device is determined by the action of the capacitive voltage divider. Eventually, a frequency is reached such that the reactance across the loading resistor causes a mismatch in the termination of the transmission line. The standing wave ratio is then so high that the meter readings are inaccurate.

c. INDIRECT R-F POWER MEASUREMENT.—Because direct methods of measuring r-f power are ineffective when the frequency of the r-f energy becomes high, a large number of indirect methods have been devised. These methods usually convert the r-f power under test to another form of energy, such as light or heat, which can be more easily evaluated. The secondary energy produced must be related to the r-f energy, and it is also necessary to consider the associated time interval in order to determine the r-f power.

(1) LAMP-LOAD METHODS. — This method of measuring r-f power was described in paragraph 2-6.*a.*(3). At the high frequencies, r-f power measurement procedure requires the proper termination of the line delivering the power. For example, if the termination of a 50-ohm line is required and conventional 28-volt 4-watt lamps are to comprise the load, then three lamps can be connected in parallel to provide approximately a 65-ohm, 12-watt termination. The hot resistance of these lamps is 196 ohms. These conditions characterize Dummy Antenna TS-78/U. As a rule the slight mismatch that results is trivial. It is interesting to note that as the lamps are dimmed, their resistance decreases and further minimizes the small mismatch. As the parallel resistance falls below 50 ohms, however, the mismatch becomes increasingly worse.

The graph in figure 3-17 shows that the light intensity of incandescent lamps can be correlated to power. If the human eye were capable of accurately distinguishing between different light intensities, this graph would provide a direct means

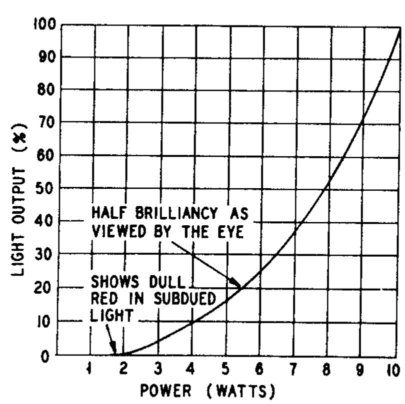


Figure 3-17. Typical Graph of Light Output Versus Power for an Incandescent Lamp

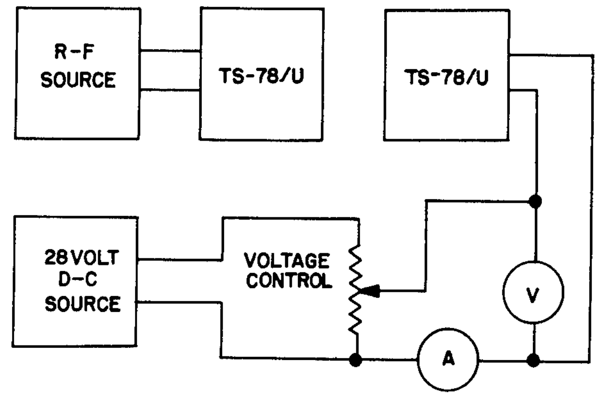


Figure 3-18. Test Setup for Lamp-Load Method of Indirect Power Measurement

of power evaluation. It is possible, of course, to measure the light intensity by use of test instruments, and then refer to a graph similar to the one shown in figure 3-17, but ordinarily this procedure is not utilized. Instead, a pair of identical lamp combinations, such as the TS-78/U equipments shown in figure 3-18, is used. One lamp load is energized by the r-f source, and the other by a 28-volt d-c power source. If the two banks of lamps are located adjacent to each other and the potentiometer across the d-c source is adjusted, it is possible to judge rather accurately when the intensities of the lamp banks are equal. This method is practical because the eye is reasonably sensitive to relative brilliance, in contrast to its fallibility when estimating absolute intensity. When the two sets of lamps appear equally bright, the product of the voltmeter and ammeter readings is equal to the r-f power.

When greater accuracy is desired, the uncertainties of visual observation can be avoided by the application of the technique illustrated by figure 3-19. By means of a tunable matching network, a lamp load is matched to an r-f transmission line. This condition is indicated by maximum brightness. The light is directed upon a photoelectric cell, which then passes a current on to a meter calibrated to read in watts. This calibration is sometimes recorded on a chart. If multiple ranges

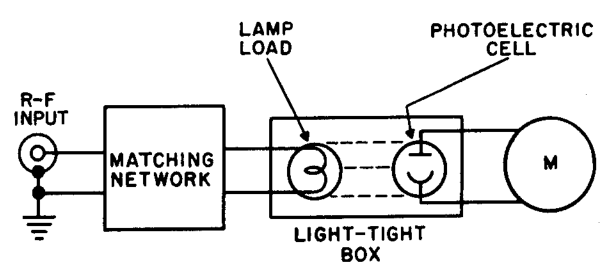


Figure 3-19. Diagrammatic Setup for Photoelectric-Type Lamp-Load Power Test

of power are desired, there must be lamp banks of suitable ratings. A test instrument of this type is the TS-70/AP, which is accurate to 10 percent or better in the frequency range of 200 mc to 750 mc. It must be connected to a 50-ohm line.

Power measurement by the lamp method involves two main considerations. First, the wattage rating of the total lamp load should be greater than the power under measurement. Second, the net resistance of the load should approximately match the impedance of the r-f source. Two additional examples of resistances (hot) are as follows: the #47 dial lamp, which is 42 ohms; and the 40-watt, 115-volt lamp, which is 330 ohms.

(2) RESISTOR-LOAD METHOD.—An effective method of measuring power indirectly is to measure the temperature rise of, or the heat generated by, a noninductive resistor acting as a load for the r-f power source. A matching network is necessary only if the loading resistance does not correctly terminate the transmission line from the r-f source. A typical procedure for measuring the heating effect of the resistor consists of passing a stream of air around the resistor. The temperature rise of the air can then be determined by thermocouples, as shown in figure 3-20. To evaluate the r-f power dissipated in the resistance, it is necessary to know the rate of air flow as well as the temperature rise. A refinement of this method is the insertion of a load resistor in an airtight box containing an inert gas. This provision enables the resistor to be operated at high temperatures indefinitely without undergoing changes in its characteristics. A power meter of this type is the TS-206/AR, which is accurate to within 10 percent up to 1 kw in the 60-mc range, if used with a 50-ohm line.

Another method of measuring r-f power consists of rectifying the r-f voltage and applying the d-c output to a meter calibrated in watts. Sometimes an electronic voltmeter is used to indicate peak power, which can be converted to average power by multiplying it by the duty cycle. In this category is the ME-6A/U, which is intended for frequencies between 400 mc and 500 mc. It is accurate to within 15 percent.

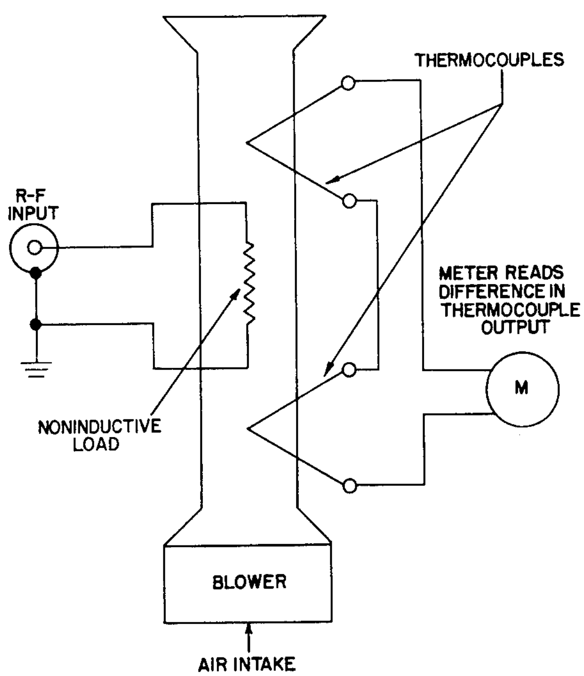


Figure 3-20. Diagrammatic Setup for Resistor-Load Power Test

(3) BOLOMETER METHODS.—Since none of the methods described previously are effective in the u-h-f range of the frequency spectrum, a test equipment employing a bolometer has become the standard instrument for power measurements in this range. At lower frequencies simpler methods are desirable, even though there is no frequency restriction on the use of bolometers.

Essentially, the bolometer is a loading device that undergoes changes of resistance as changes in dissipated power occur. There are two chief types of bolometers, the barretter and the thermistor. The barretter is characterisized by an increase in resistance as the dissipated power rises, but the thermistor decreases in resistance as the power increases. In the case of either device, resistance is measured before and after the application of r-f power. If the same change in resistance is then produced by a variable d-c source of power, the r-f power is equal to the measured d-c power. This relationship makes possible the calibration of a bridge circuit directly in units of power. In other words, there is one condition of balance when no r-f power is applied, but in the presence of power there is a second condition of balance owing to the resistance change of the bolometer. It is this change of resistance that is calibrated in power.

(*a*) BARRETTER APPLICATION.—The structure of a typical barretter is shown in figure 3-21. The fine wire (usually tungsten) is extreme-

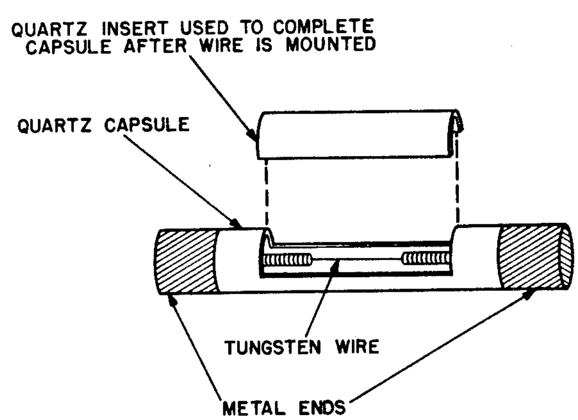


Figure 3-21. Typical Barretter

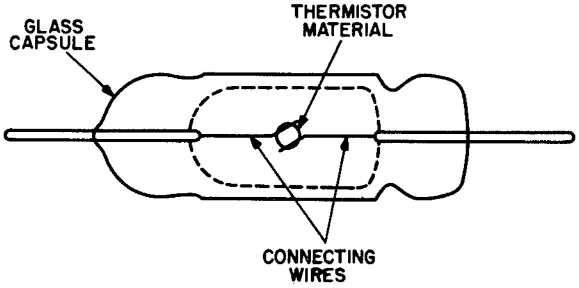


Figure 3-22. Bead-Type Thermistor

ly small in diameter, so that it is possible for the r-f current to penetrate to the center and thereby minimize skin effect. It is supported in an insulating capsule between two metallic ends, which also act as connectors. Because of these physical characteristics the barretter resembles a cartridge-type fuse. The enclosure is a quartz capsule made in two parts, the second part of which is an insert cemented in place after the tungsten wire has been mounted. In operation, the barretter is matched to the r-f line after the r-f power is applied. At low levels of power, the resistance-versus-power curve of the barretter is characterized by a square-law relationship.

(*b*) THERMISTOR APPLICATION.—A high degree of precision is made possible by the thermistor, and consequently it is widely used. The negative temperature coefficient comes from the use of a semiconductor as the active material. Figure 3-22 shows a predominant type of construction. Note that the active material is shaped in the form of a bead, which is supported between two pigtail leads by connecting wires. The pigtail ends are imbedded in the ends of the surrounding glass capsule. A basic thermistor bridge circuit is shown in figure 2-33; refer to paragraph 2-6.*a*.(4)(*a*) for a discussion of its operation.

A thermistor bridge circuit frequently includes other thermistor elements, called compensating thermistors. These thermistors respond to fluctuations of ambient temperature so that the bridge balances, and hence the calibration is maintained over a wide temperature range. Compensating thermistors are usually in disc form so that they can be mounted upon a flat metal surface such as a chassis or wave guide.

The negative-resistance temperature coefficient of thermistors is desirable, because excessive power has the effect of changing the resistance of the thermistor to an extent that causes a pronounced r-f mismatch. The resulting decrease in power transfer reduces the likelihood of burnout.

(*c*) BOLOMETER LIMITATIONS.—The barretter and thermistor type of test instruments are limited by the extremely low power which they are able to dissipate. A rating of 1 milliwatt has been standardized, however these devices can be operated at power up to 10 or even 20 milliwatts. If the use of a low-power bolometer is required in a high-power measurement, some attenuating device must be employed. In the u-h-f range of frequencies, some form of wave guide can readily be made to serve this function. One common method is to utilize a section of wave guide which is operated substantially below its cutoff frequency. The exact amount of attenuation per unit width is usually known; a value of 30 db is typical. By the term "per unit width" is meant a distance along the length of the wave guide equal to the width of the section in use. Another type of attenuator is the resistive type of wave guide. In this attenuator a glass strip, coated with either a thin film of platinum or some other stable metal, is extended along a section of wave guide. The strip is moved laterally by means of either a spring-loaded cam or a leadscrew drive mechanism, which is driven by a control shaft geared to a dial which is calibrated in units of attenuation. Devices of this type now in use have a maximum attenuation of 40 db, accurate to within 0.5 db. Cutoff wave-guide attenuators, on the other hand, do not have comparable stability or accuracy, but easily provide up to 100 db of attenuation.

Since a calibrated attenuator is generally used with a thermistor bridge, it is customary to attenuate the input signal to a known reference level, such as 1 milliwatt or 6 milliwatts. Power referred to 1 milliwatt as a reference level is expressed in dbm.

d. TESTING TECHNIQUES—HIGH-POWER APPLICATIONS. — The design of high-power radar systems for operation in the s-h-f region of the spectrum has necessitated the development of new techniques for measuring large amounts of r-f power. One widespread practice is the sampling technique, in which a small, known portion of the total power is removed for monitoring purposes. This procedure enables the power meter to be operated at a low level. Some representative sampling devices are the r-f probe, the directional coupler, the power divider, and the pickup antenna. Use of any sampling device requires that the coupling loss be accurately known, and that this loss stay fixed at a constant, stable value. Measurements of this type are discussed in detail in the paragraph titled RADAR TESTING—POWER MEASUREMENTS.

(1) WATER-LOAD METHOD. — Accurate measurements of high-power microwave energy can be achieved by means of a water load. As illustrated in figure 3-23, water is contained in a water-tight section of wave guide by a dielectric partition. Reflections are minimized by slanting the partition across the wave guide so as to present a tapered surface to the power flow. In addition a matching section is adjusted to provide a mini-

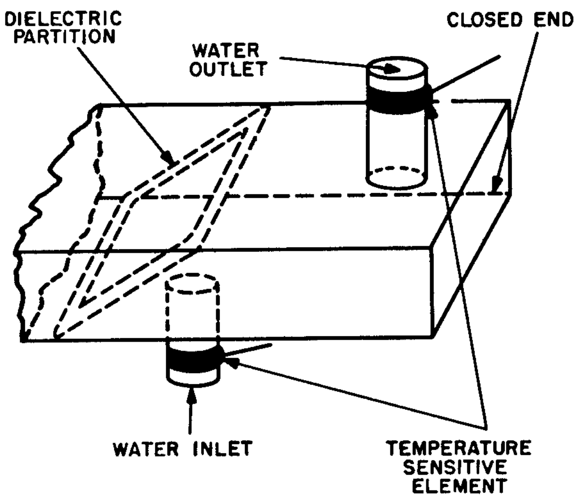


Figure 3-23. Diagrammatic Setup for Water-Load Power Testing

mum standing-wave ratio. Water is then pumped through the load section of wave guide at a carefully measured rate, and a temperature-sensitive element is located at both the intake and outlet valves. Any difference in temperature indicates the amount of heat absorbed by the water from the r-f energy. Since the temperature rise of a volume of water over a period of time is accurately known, the r-f power can be computed. Equations for the computation are available in basic physics books. The water-load method of power measurement is considered too complex for use other than calibration.

(2) GAS-LOAD METHOD. — A simpler method of measuring high-power r-f energy is shown in figure 3-24. This device incorporates a gas load that is held in a section of wave guide by a dielectric window comparable to the one shown in figure 3-23. Maximum power absorption is

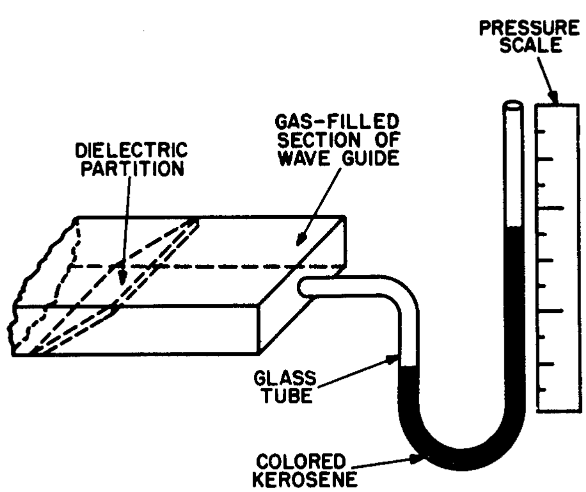


Figure 3-24. Diagrammatic Setup for Gas-Load Power Testing

again accomplished by a matching device. As the temperature of the gas (usually ammonia) rises, there is a corresponding increase in pressure. To measure the gas pressure, a manometer tube is attached to the wave guide. Increased pressure forces colored kerosene from the bottom of the manometer upward along the accompanying scale. It is by means of this indication that the r-f power can be determined.

(3) SAND-LOAD METHOD. — The sand-load method of high-power measurement, which is similar in many respects to the resistor-load method employed at lower frequencies, utilizes a sand load surrounding a temperature-sensitive element. When a mixture of sand and an appropriate amount of aquadag is placed in a section of wave guide, and the surface of the mixture exposed to the r-f energy is properly tapered, there will be a satisfactory transfer of power to the sand load without necessitating a matching device. The temperature rise of the load over a period of time can then be readily converted to power.

3-6. TRANSMITTER TESTING—ADDITIONAL MEASUREMENTS.

The text which is included under the above title deals with additional tests and measurements customarily made at or near a transmitter. These tests and measurements cover specifically the subjects of amplitude modulation, frequency modulation, field intensity, and distortion at the transmitter. Some applications of the grid-dip meter are also discussed to illustrate the versatility of the instrument.

a. AMPLITUDE MODULATION MEASUREMENTS.—In paragraph 2-9.*b.*(2) a formula was presented from which the percentage modulation was derived using the designations shown in figure 2-60. Presented now in a slightly modified form this formula is expressed as:

$$\text{Modulation percentage} = 100\ (E_{max} - E_o)/E_o$$

where E_{max} represents the highest peak voltage, and E_o is the unmodulated carrier voltage. The application of this formula presupposes that the modulating voltage is a pure sine wave. Normal broadcasting, however, is characterized by complex envelope patterns, and in this light the definition is ambiguous. Consequently, it is advisable to regard the preceding expression as the percentage of positive peak modulation. When the minimum voltage (E_{min}) rather than the peak voltage (E_{max}) is used to compute percentage modulation, then the computed percentage is regarded as negative peak modulation. This is shown by the following formula:

$$\text{Modulation percentage} = 100\ (E_o - E_{min})/E_o$$

Since the above two modulation percentages often differ, it is useful to define the average percentage of modulation as $100\ (E_{max} - E_{min})/2E_o$.

It is evident from the preceding definitions that methods of measuring all three types of modulation percentages must be devised. When different values are obtained, however, the cause may not necessarily be attributable to unequal positive and negative peaks of a complex modulating wave. Another possibility is a type of distortion which is caused by carrier shift. In addition, distortion may be present which is produced by effects other than the modulation process. Some examples are parasitic oscillation, nonlinear r-f amplification of modulated signals, and distortion present in the audio amplifiers. These possibilities show that modulation measurements can sometimes be worthless even though they appear entirely normal.

Unfortunately, continuous variation of the modulation percentages creates a number of additional problems. For example, there is a need for damping, so that a meter can provide an average reading despite the fluctuations. An average reading, on the other hand, will not disclose the presence of momentary overmodulation. This shortcoming is serious, owing to the large number of sideband frequencies produced, in addition to the normal ones, whenever overmodulation occurs. Not only do these extra frequencies interfere drastically with other transmissions, but they also distort the modulation signal reproduced at the receiver. These considerations account for the necessity of a meter that responds to modulation peaks. Specifically, both positive-peak and negative-peak overmodulation must be indicated. Positive-peak overmodulation occurs when the positive modulation percentage exceeds 100, and negative-peak overmodulation occurs when the negative modulation percentage exceeds 100.

The foregoing discussion shows that the problem of modulation measurements consists of diverse factors requiring separate investigation. There are test instructions available which make possible the rapid determination of all modulation characteristics. Since the details of specific test equipment are explained in literature which is supplied by the manufacturer or from other sources, no one specific test equipment will be described in the text to follow. Instead, the discussion will be limited to basic circuits used for determining the various modulation properties. This discussion will make clear the general nature of the modulation problem, and will provide the basis for understanding the circuits of more refined test equipment.

(1) WAVE COMPONENT SEPARATION METHOD.—Inspection of part (A) in figure 3-25 will disclose that, with respect to either the positive or negative half cycles, the average value of a carrier perfectly modulated by a true sine wave is the same as the average value of an unmodulated carrier. This statement presumes an interval at least as long as the period of the sine wave. (It should be known, of course, that the average value of either wave shown in part (A) of figure 3-25 is equal to zero.) These properties of an amplitude-modulated wave suggest that this wave should be rectified and the resulting d-c and a-c components separated by appropriate filtering. This concept of determining modulation percentages is evolved in the three parts of figure 3-25. In part (A) both an unmodulated and a symmetrically modulated wave are shown. Part (B) shows what is left after rectification of the carrier. The sine wave shown in part (C) can be interpreted as the variation of peak values of the rectified sine waves, or the variation of average values, depending on the type of filter used to remove the r-f variations. For example, a capacitor input filter would provide an output nearly equal to the peak values, while a choke input filter would yield an output more nearly equal to average values. In either case, the a-c component of the waveform shown in part (C) is a replica of the modulating signal. The average value, that is, the d-c component of the waveform, is proportional to the carrier and is independent of the percent of modulation when the modulation signal is symmetrical; similarly, the amplitude of the a-c component is proportional to the amplitude of the modulating signal.

(*a*) CIRCUIT ANALYSIS.—Figure 3-26 shows a basic circuit for the measurement of modulation percentages using the wave-component separation method. This circuit uses a short antenna, along with inductor L and capacitor C which comprise a resonant circuit tuned to the frequency of the radio wave under test. A diode detector, coupled to the tuned circuit by a capacitor C1, rectifies the radio wave. If the r-f filter is disregarded for the moment, the action of the diode can be explained as follows: Because of the manner in which the diode is connected, capacitor C1 quickly charges during negative half cycles through the low resistance path offered by the diode. The polarity of C1 is indicated in the figure. Since capacitor C1 is comparatively small in value, the current actually flowing through the diode is low, and the loading imposed on the tuned circuit is slight. The voltage applied to the remainder of the circuit during the negative half cycles is practically zero, because the voltage across the tuned circuit is offset by nearly equal voltage across capacitor C1. As the signal voltage swings positive, however, capacitor C1 discharges through the other circuit components. Therefore, only positive half cycles are passed on to the remainder of the circuit. An alternate means of achieving the same result would be to connect the diode at the point now occupied by capacitor C1, the plate being connected to the tuned circuit. With the choke input filter present in the circuit, as shown in figure 3-26, the r-f variations in the rectified positive

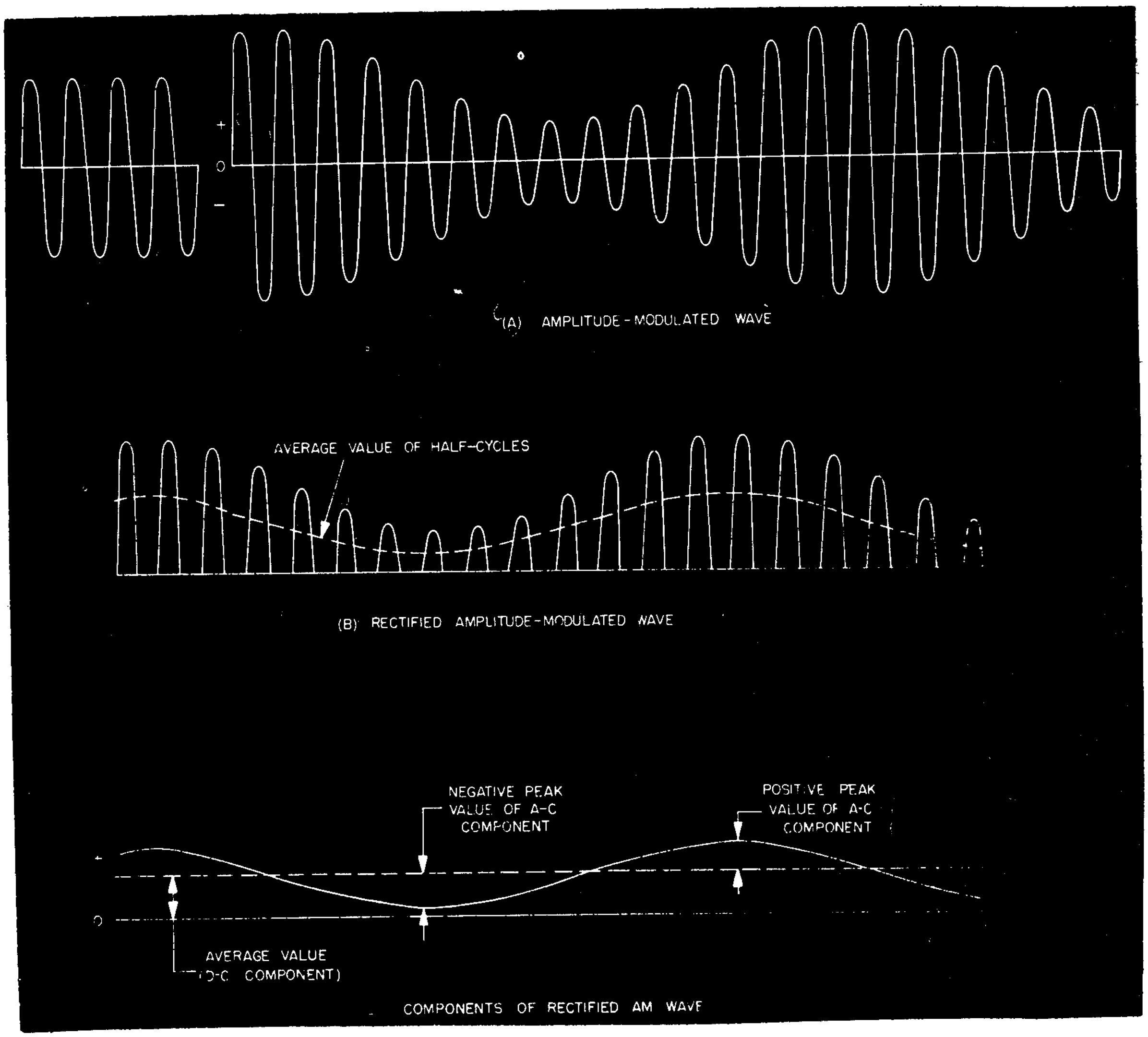


Figure 3-25. Separation of Amplitude-Modulated Wave into Components

half cycles are smoothed out. Consequently, the two final branches of the circuit receive a fluctuating d-c signal consisting of the modulating signal (a-c component) and an average value (d-c component). The filter arrangement of the two branches then separates the respective components. For example, the d-c component can pass through the inductance of the d-c branch but is blocked by the capacitor of the a-c branch. The a-c component, on the other hand, is admitted by the capacitor into the a-c branch but is rejected by the inductor of the d-c branch. It is evident that if meter M1 is a d-c meter, its reading will be proportional to the carrier, and if meter M2 is a fairly high resistance a-c meter, its reading will be proportional to the original modulating signal. More exactly, an a-c meter indicates the effective value of the a-c component.

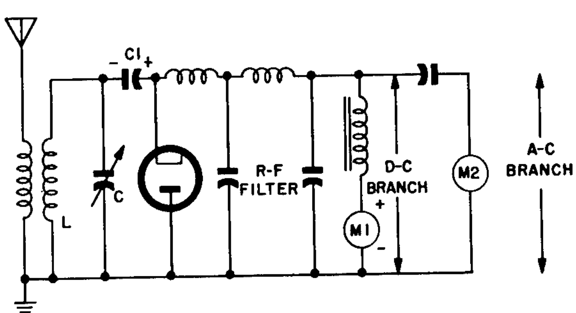


Figure 3-26. Circuit Used for Measuring Modulation Percentage by Wave-Component Separation Method

(*b*) INTERPRETATION OF READINGS.—The condition of complete modulation will be discussed first, in order to interpret the readings of the two meters. For complete modulation, the peak value of the fluctuating d-c wave, which is shown in part (C) of figure 3-25, is equal to twice the average value, and the minimum value

is zero. If the length and position of the antenna were such that there was full-scale deflection of meter M1, then meter M2 would indicate 0.707 of the voltage represented by full-scale deflection of meter M1. Suppose the antenna were readjusted so that meter M1 indicated 0.707 of full-scale deflection. Meter M2 would now indicate half-scale deflection, 50 volts if the scale were calibrated from 1 to 100 volts. The corresponding reading on meter M1 would be 70.7 volts. These considerations show that by adjusting the antenna for a reading of 70.7 volts on meter M1, the voltage reading on meter M2 will be such that multiplication by two gives the percentage of modulation. Since 50 volts, which corresponds to complete modulation, is the maximum reading possible when M1 is initially adjusted to 70.7 volts, it is desirable that full-scale deflection of meter M2 indicates 50 volts.

Reasoning in the same manner, it is apparent that if meter M1 is adjusted to 141.4 volts, then meter M2 will read 100 volts when the percentage of modulation is 100. Under this circumstance, the reading of meter M2 will indicate the modulation percentage directly. Unfortunately, it is not always possible to obtain voltages sufficiently high to make this adjustment feasible.

The resistance in the d-c branch should be about 100,000 ohms. This requirement suggests the use of a 0—100-volt meter with a resistance of 1000 ohms per volt or greater. To measure the a-c component, a high-resistance a-c meter can be utilized. It should be accurate over the entire audio range and should have a sensitivity of at least 1000 ohms per volt. When a conventional a-c meter is used, the component method yields an average modulation percentage; it is not capable of disclosing either the positive or negative percentage of modulation, because an a-c meter measures the effective, or r-m-s value of an a-c signal, not the peak value. Furthermore, the readings obtained are valid only when the modulating signal is a sine wave, as has been assumed throughout this discussion.

When the modulating signal is a complex wave, it is advisable to use a peak-reading electronic voltmeter to measure the a-c component. In this case, both the a-c and d-c meter readings will be alike when the modulation is complete. If the voltmeter responds quickly to continuous variations of the peak value of a signal, the instantaneous percentages of modulation, positive or negative according to the voltmeter, will be indicated continuously.

(2) DOUBLE-RECTIFIER METHOD.—The circuit shown in figure 3-27 is a simple arrangement for measuring peak modulation. Up to the part of the circuit designated by points A and B, the circuit is essentially the same as that of figure 3-26. Diode V1 is connected so that the cathode is grounded. This setup leads to the development

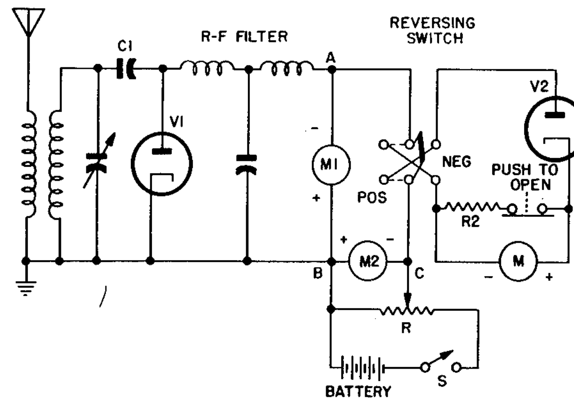


Figure 3-27. Circuit Used for Double-Rectifier Method of Modulation Measurement

of negative half cycles across points A and B. Meter M1 should be a high-resistance voltmeter. Across it will be a pulsating voltage such as the waveform shown in part (C) of figure 3-25.

In series with the voltage across M1 is a variable d-c voltage, as determined by the setting of potentiometer R1 connected to the battery. Switch S is provided to prevent discharge of the battery when the modulation meter is not in use. Meter M2 indicates the amount of voltage effective between points B and C. The polarity of this voltage is opposite to that of the pulsating direct voltage, causing the difference of the two voltages to appear between points A and C. These points are connected to a reversing switch.

The second rectifier circuit, consisting of diode V2, meter M, and the push-button shunting circuit, is energized by the difference voltage present between points A and C. With the reversing switch in the position indicated by the dotted lines, point C must be positive with respect to point A for current to flow through meter M. This condition occurs when the pulsating direct voltage exceeds the battery voltage during any portion of the cycle. If potentiometer R1 is adjusted carefully until the current flow through meter M just begins, the reading of meter M2 closely equals the maximum value of the rectified modulated wave. This is the positive modulation peak.

When the reversing switch is in the second position, there can be a deflection of meter M only if point A becomes positive with respect to point C. This condition is most likely to occur at the smallest absolute value of the negative rectified signal, or, in other words, at the instant of a negative peak of the modulating signal. Therefore, the negative modulation peak can be read on meter M2 provided the potentiometer is adjusted so that current just begins to flow through meter M.

Meter M1 provides a reading of the carrier voltage. It should remain connected between points A and B throughout the testing procedure in order to prevent changes in the rectified carrier voltages.

Meter M2 is required to provide a reading of the battery voltage. The different percentages of modulation are found by using the appropriate equation of those listed below:

Positive modulation percentage$=100(E_p—E_c)/E_c$
Negative modulation percentage$=100(E_c—E_n)/E_c$
Average percentage$=100(E_p—E_n)/2E_c$

where: E_p=positive modulation peak voltage indicated on meter M2
E_n=negative modulation peak voltage indicated on meter M2
E_c=carrier voltage indicated on meter M1

(*a*) TEST LIMITATIONS.—It is important to realize that the values obtained by this method are slightly inaccurate. Specifically, the negative measurements are somewhat high and the positive measurements are somewhat on the low side. This condition has come about because it has been assumed that diode V2 is able to conduct with no potential difference between the plate and cathode. For the diode current to be detectable, however, some potential difference must exist. It follows that, during a measurement of the positive modulation peak, the reading of meter M2 must be slightly less, rather than exactly equal to the maximum rectified voltage at the time V2 just begins to conduct. By the same reasoning, the reading of M2 must be a little greater than the minimum rectified voltage in order to permit conduction of V2 during measurement of the negative modulation peak. The error becomes smaller as the sensitivity of meter M increases and the amplitude of the rectified carrier voltage increases. The power which the modulation meter absorbs from the transmitter should be as high as possible, but not excessive. An accuracy of 2 percent can be attained by using a meter with a 200-microampere movement in the presence of a 50-volt rectified carrier. During any measuring procedure, the microammeter must be protected by a heavy shunt. After a preliminary adjustment of potentiometer R1 has been made, the shunt should be removed by the push-button switch. A precise setting may now be made without fear of damaging the meter. It is imperative that these instructions be observed, otherwise the microammeter may be ruined before a reading can be taken.

Another limitation of the double-rectifier method of modulation measurement is its inability to give a continuous indication of the modulation. Consequently, this method is not suitable for monitoring purposes.

(3) MONITOR METER METHOD.—In monitoring applications, a modulation meter should indicate the percentage of modulation directly and continuously. One method which provides continuous readings is shown in figure 3-28. The circuit presented is a double rectifier circuit modified by the addition of a capacitor, a resistor, and a more sensitive microammeter calibrated directly in percentage of modulation.

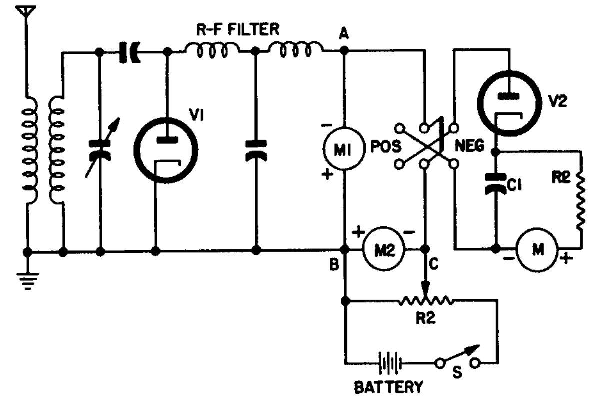


Figure 3-28. Circuit for Modulation Measurement Using the Monitor Method

(*a*) CIRCUIT ANALYSIS.—In this setup, potentiometer R1 is adjusted until meters M1 and M2 indicate the same readings. For this application, meters having a deflection sensitivity of 1000 ohms per volt are acceptable. Since the battery voltage opposes the rectified voltage, the voltage across points A and C alternates in accordance with the modulation signal. The negative half cycles between points A and C correspond to the positive modulation peaks, while the positive half cycles correspond to the negative modulation peaks. Consequently, conduction in diode V2 is caused by the positive modulation peaks when the reversing switch is thrown in the left-hand position, and by the negative peaks when the switch is in the right-hand position. During conduction in diode V2, capacitor C1 charges quickly to the peak value of the modulation signal. This is possible because the only charging resistance consists of a portion of the potentiometer and the internal resistances of the two rectifier tubes. When diode V2 is cut off, C1 must discharge through meter M and resistor R2. In order to keep the voltage across C1 nearly equal to the peak of the modulation signal, R2 is made large, and successive modulation peaks can easily replenish the small charge lost. The condition is illustrated in figure 3-29. When the first half cycle arrives, the capacitor is nearly charged to the maximum value. Between peaks it discharges very slowly, so that the second half cycle raises the voltage to virtually the peak value. If the third peak is lower, it has no effect upon the capacitor. In general, the capacitor voltage is not only almost equal to the peak voltages of the rectified half cycles, but also undergoes only small variations. This means that the meter reading is fairly staple, increasing

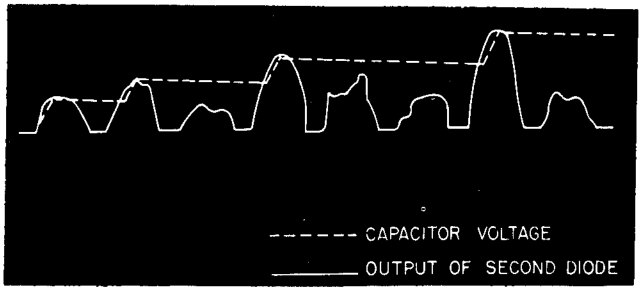


Figure 3-29. Capacitor Action in Second Diode Circuit

sharply when an extreme peak arrives, and then decreasing slowly. As a result, the device is highly satisfactory in monitoring service.

(4) SLIDE-BACK ELECTRONIC VOLTMETER APPLICATION.—The slide-back type of electronic voltmeter has served as a modulation meter for many years. A practical circuit arrangement is given in figure 3-30. Excitation for the device is derived from a tuned circuit suitably coupled to the transmitter. This device does not disclose any information as to the symmetry of the modulated wave.

(*a*) TEST PROCEDURE.—To determine the percentage of modulation using a slide-back electronic voltmeter, proceed as follows:

1. Adjust potentiometer R1, so that the voltmeter M1, indicates zero volts, and adjust potentiometer R2 so that the milliammeter M, indicates zero plate current through the tube.

2. Now adjust the tuned circuit so that the amplitude of the unmodulated carrier signal is sufficiently great to cause a convenient deflection of milliammeter M. Half-scale deflection at least should be produced.

3. Adjust potentiometer, R1, so that the tube is again cut off, as indicated by zero deflection of meter M. The reading of meter M1 now equals the peak voltage of the r-f signal in the tuned circuit. This voltage, in turn, is proportional to the unmodulated carrier current, and should be recorded.

4. Without disturbing the tuned circuit, modulate the carrier signal with a sustained sine wave. Once again, adjust R1 until the tube is just cut off. The new reading of meter M1 is proportional to the peak value of the modulated current, and should also be recorded.

5. The percentage of modulation can now be computed from the following formula:

$$\text{Percentage of modulation} = 100(E_{max} - E)/E$$

where: E_{max} = second reading of meter M1
E = first reading of meter M1

(5) NEGATIVE-PEAK OVERMODULATION INDICATOR.—Sometimes it is convenient to incorporate in the transmitter a meter that indicates when negative-peak overmodulation occurs. A satisfactory arrangement consisting of a diode and a milliammeter is shown in figure 3-31. Plate circuit modulation of an r-f amplifier by means of a transformer is assumed. Ordinarily, the cathode potential of the diode is positive and the tube is cut off. When the amplitude of the signal developed by the modulator is excessive, however, the cathode of the diode swings negative. This is the condition of negative-peak overmodulation, and is immediately indicated by a deflection of meter M.

(6) CARRIER-SHIFT INDICATOR APPLICATION.—At the beginning of the discussion

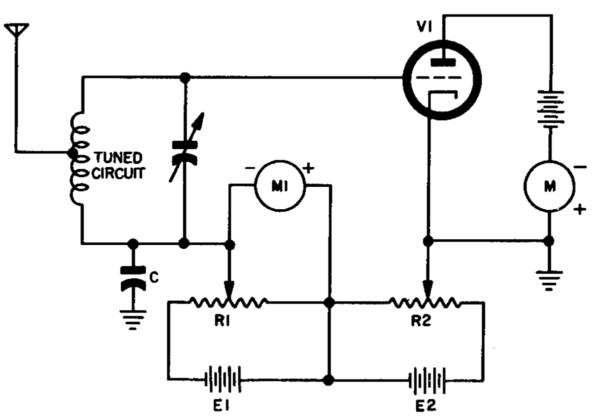


Figure 3-30. Circuit for Modulation Measurement Based on Slide-Back Electronic Voltmeter

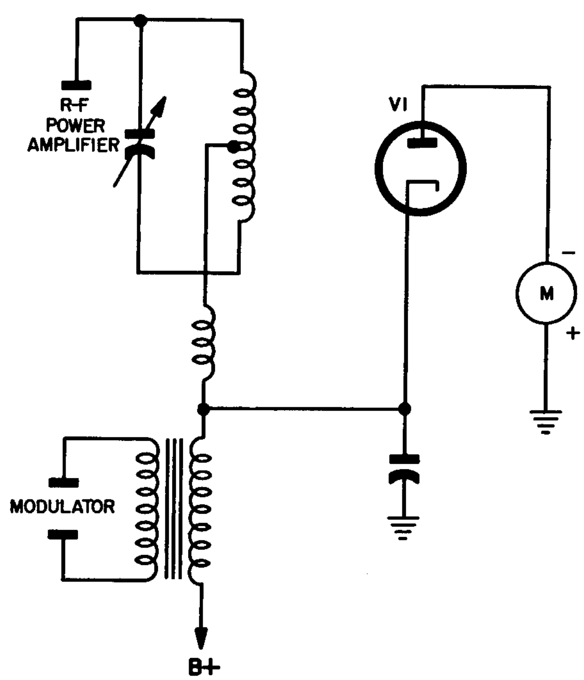


Figure 3-31. Circuit of Negative-Peak Overmodulation Indicator

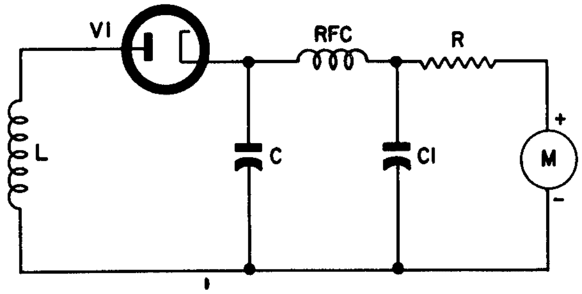


Figure 3-32. Circuit of Carrier-Shift Indicator

about modulation, it was stated that when the positive and negative modulation peaks are unequal, that there is an effective shift in the amplitude of the carrier. This shift is upward when the positive peaks are disproportionate, and downward when the negative peaks predominate. Under these circumstances, the average value of half cycles is not proportional to the carrier, as previously discussed under the wave component separation method of measuring modulation.

(*a*) CIRCUIT ANALYSIS.—The simple diode-detector circuit shown in figure 3-32 takes advantage of this effect and therefore indicates when carrier shift occurs. In this figure, inductor L represents the means by which the signal is transferred from the r-f stage to the diode circuit for monitoring purposes. The r-f component of the signals rectified by the diode is filtered by the choke and capacitors, and the peak value of the half cycles is impressed across resistor R and meter M. The effect of R is to improve the linearity of rectification. While the carrier is unmodulated, the coupling of the circuit should be adjusted to produce a convenient deflection of meter M, at least half scale. If the signal is modulated, the meter reading remains unchanged as long as the modulation is symmetrical. If carrier shift occurs, there is a movement of the pointer. A movement toward a higher reading indicates positive carrier shift, and a movement toward a lower reading indicates negative carrier shift.

(*b*) ALTERNATE METHOD.—Although less accurate, a d-c milliammeter connected in the plate circuit of a modulated r-f amplifier is also capable of revealing carrier shift. This may be seen from the following explanation. A plate-modulated class C amplifier is referred to as a constant current system of modulation. This term has arisen because most plate-modulated amplifiers are adjusted so that the plate-supply current varies in proportion to the effective plate-supply voltage. When there is no modulation, this voltage is simply equal to the battery, or rectifier, voltage. In the presence of a modulating signal, the effective plate supply becomes the sum of the modulating signal and the battery voltage. Since the average value of a sine wave is zero, it follows that the average plate current remains proportional to the battery voltage whether there is modulation or not. Assuming ideal conditions, a meter in the plate-supply lead therefore indicates a constant amount of current, regardless of modulation. It must be remembered, however, that in actual operation the proportionality between plate current and plate-supply voltage may not be exact for all percentages of modulation, particularly the higher ones. This condition means that the reading of a plate-current meter probably will vary moderately as the modulation percentage is increased to its maximum of 100 percent. Nevertheless, the meter reading is a fairly reliable indication of carrier shift, since a relatively large change of deflection, either downward or upward, occurs when the modulation is not symmetrical.

(7) OSCILLOSCOPE TECHNIQUES.—Because of the highly instructive patterns obtainable from modulated waves, the cathode-ray oscilloscope has proved extremely useful as a continuous modulation monitor. Up to a point, the oscilloscope can even serve as a measuring device, but it is limited in this application by lack of accuracy. For example, the relative error of most measurements taken with a 5-inch cathode-ray tube is about 10 percent. Although such accuracy may be sufficient for many maintenance checks, the oscilloscope is usually considered more valuable as a monitor of general modulation conditions. It is also utilized to make photographic records.

(*a*) TRAPEZOIDAL PATTERNS.—Refer to paragraph 2-9.*b*.(2) for a discussion concerning modulation measurement using trapezoidal patterns. A trapezoidal pattern is obtained by applying the modulated wave to the vertical deflection plates and the modulating signal to the horizontal-deflection plates. The resulting pattern is stationary and its shape is determined by the percentage of modulation. An example of a trapezoidal pattern showing 50 percent modulation is given in figure 2-60.

The presence of an abnormal pattern does not mean necessarily that there is a defect in the operation of the transmitter. A pattern with elliptical sides merely implies that with respect to the signals applied to the oscilloscope, there is a phase difference between the modulating signal and the modulated r-f signal. The curved appearance of the sides is simply a Lissajous effect denoting the phase difference. In fact, the straight sides of a properly formed trapezoid simply represent the characteristic Lissajous pattern of a zero phase difference. When the modulating signal is not a sine wave, a trapezoid is still formed, but there is a series of bright vertical bands in the pattern. These bands indicate points at which the lateral motion of the electron beam is relatively slow.

(*b*) WAVE-ENVELOPE PATTERNS.—Another useful procedure for monitoring an AM transmission is to apply a sawtooth sweep voltage to the horizontal-deflection system while the r-f signal is applied to the vertical. A resultant pattern of this type is illustrated in figure 2-59. For sine-wave modulation displays, the sweep frequency should be equal to, or a multiple of, the modulation frequency, in order to provide a stable pattern. Even during normal transmissions, a sweep frequency of 256 cps or a submultiple usually produces a stationary pattern. When the percentage of modulation is of primary interest, a low sweep frequency, such as 32 cps should be used. On the other hand, if it is necessary only to examine the wave shape of the modulation, a higher frequency should be used.

The use of a 60-cycle sine-wave sweep voltage is helpful only occasionally. The principal recommendation for this method is its simplicity, as no cumbersome connections are required. Unfortunately, a stationary pattern rarely occurs during normal transmission. The usual result is such obscurity that very little useful information can be learned. About the only definite indication is that of negative-peak overmodulation, which is momentarily indicated by a bright horizontal line. Whenever bright horizontal flashes are seen, therefore, overmodulation has occurred.

b. FREQUENCY MODULATION MEASUREMENTS.—As explained in section 2, paragraph 2-9.*a.*(2), the concept of percentage of modulation as discussed in connection with amplitude modulation does not apply to frequency modulation. Instead, the two predominant factors influencing the transmission characteristics of FM are the frequency deviation and the modulation index. The relationship of these quantities is shown by the following equation:

$$m = \frac{F_d}{F_m}$$

where: m = modulation index
F_d = frequency deviation
F_m = frequency of modulating signal

By means of this basic relationship, it is possible to determine the frequency deviation when the modulation index and the modulating frequency are known.

Despite the foregoing remarks, it is possible to make an analogy between percentage of modulation and frequency deviation. Specifically, frequency deviation is proportional to the amplitude of the modulating signal, as is the percentage of modulation. The latter statement can be justified readily. Assuming perfect sine-wave modulation, the degree of modulation equals the quantity $(E_{max} - E_o)/E_o$, where E_o is the amplitude of the unmodulated carrier and E_{max} is the maximum amplitude of the carrier. Since the latter quantity is simply the sum of the carrier and the effective audio signal, it can be represented by the quantity $E_s + E_o$, where E_s denotes the amplitude of the modulating signal. Substituting this value for E_{max}, it is seen that the degree of modulation equals E_s/E_o. Hence, the degree of modulation is proportional to the amplitude of the modulating signal, as previously stated.

Because of this analogy, it is convenient to extend the concept of percentage of modulation to frequency modulation by arbitrarily designating the maximum allowable frequency deviation of a class of operation as 100 percent modulation. An important distinction to remember is that no distortion results from modulation percentages greater than 100 in FM transmissions. However, any percentage larger than the figure sanctioned by the proper authorities will produce excessive channel width, making interference with other stations possible. For example, commercial FM stations must not exceed a frequency deviation of 75 kc, and the sound transmission of television stations is restricted to a deviation of 25 kc. A simple procedure for frequency deviation measurement is discussed in paragraph 2-9.*c*. The Bessel zero method, which is discussed below, is somewhat more complicated.

(1) BESSEL ZERO METHOD.—If some of the more elaborate test equipment designed especially for monitoring FM transmissions is not available, a technique known as the Bessel zero method enables the determination of frequency deviation utilizing the following equipment: a variable-frequency (low-distortion) audio oscillator and a communications receiver tunable to the carrier frequency of the FM transmitter. The receiver must include a beat-frequency oscillator.

It was stated earlier that the modulation index, m, determines the relative amplitude of the carrier and sideband frequencies emitted by an FM transmitter. Specifically, the carrier component disappears completely for certain values of m, such as 2.405, 5.52, 8.654, etc. In other words, all of the transmitted power is contained in the sidebands. This fact, as well as the distribution of energy among the various sideband frequencies and the carrier for other values of m, is disclosed by a series obtained from Bessel functions. Although too involved for direct application, Bessel functions nevertheless are the basis of the Bessel zero method for determining the frequency deviation of an FM transmission. Fortunately, this procedure does not require any knowledge of Bessel functions in order to be utilized. It is necessary only to increase the amplitude of the modulating signal until the carrier of the FM signal disappears. The frequency deviation can then be calculated by substituting 2.405 for m in the previously given equation: Thus, $F_d = 2.405\ F_m$.

As a note of precaution when the Bessel func-

tions are being used, when the receiver beat-frequency-oscillator (b-f-o) frequency is less than the modulating frequency, as is sometimes required, it is well to avoid ratios of modulation to b-f-o frequency such as ½, ⅓, ¼, etc, to avoid possible error. For example, if the modulation frequency is to be 1000 cycles, and the bfo is adjusted to give a 500-cycle beat note with the unmodulated carrier, the application of modulation will produce another 500-cycle beat note between the bfo and the first sideband component on the b-f-o side of the carrier. Such a condition would be encountered, especially if the receiver contains appreciable distortion.

(*a*) TECHNIQUE TO FIND THE ZERO POINTS.—It has been stated that the frequency deviation of an FM transmission is proportional to the amplitude of the modulating signal. Consequently, the frequency deviation can be made larger by increasing the amplitude of the modulating signal. As the frequency deviation becomes larger, the modulation index also increases. The following paragraphs explain in a general way how these properties are utilized.

Refer to figure 3-33. The communications receiver used for the Bessel zero method of measuring frequency deviation must have a bfo, and must be tunable to the FM transmission. First, the receiver is tuned to an unmodulated transmission of the equipment under test. In order to produce an audible note, it is necessary to adjust the bfo until a tone, such as 500 cps, is plainly heard in

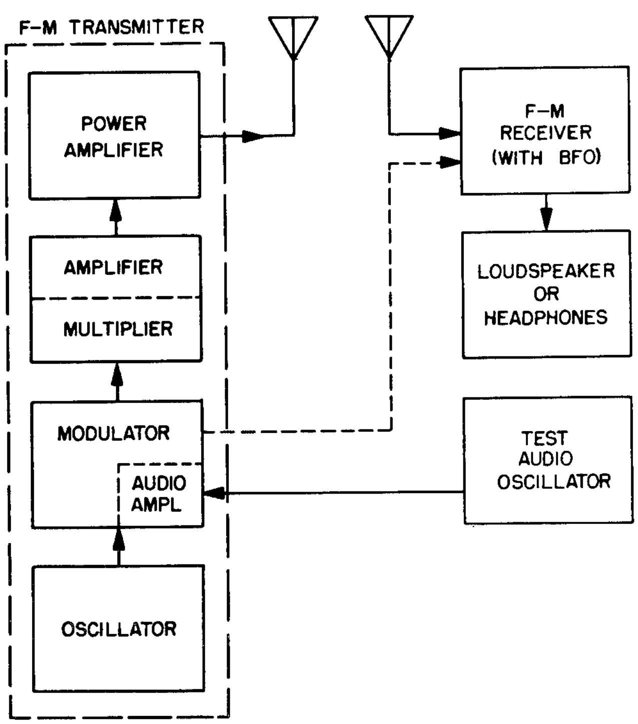


Figure 3-33. Test Setup for Measurement of Frequency Deviation by Bessel Zero Method

the output of the receiver. Once the pitch of this note is set, the bfo adjustments should be fixed so that the ear may become accustomed to this particular pitch. This is an important requisite. Later, the frequency deviation will be varied by changing the amplitude of a modulating signal, diverting power from the carrier into various sideband frequencies. As a result, many conflicting tones will be introduced in the output of the receiver, but they must be ignored completely at all times. Practice is recommended so that the technician will become adept at judging when the beat note produced by the carrier vanishes. The use of a low-pass filter is often helpful although not absolutely necessary.

An audio signal from a suitable oscillator is now applied to the audio-amplifier section of the transmitter. The output of the amplifier is applied to the modulating stage of the transmitter. If the amplitude of the signal is increased, the sideband frequencies and their innumerable beat notes are produced. Note in particular the gradual attenuation of the beat note arising from the carrier. At some point this beat note should disappear entirely, only to reappear once more as the modulating signal is increased further. In general, the modulating signal should never be increased to the point where any stage of the transmitter becomes saturated.

(*b*) ESTABLISHING A MAXIMUM FREQUENCY DEVIATION.—For purposes of discussion, suppose that a transmitter is limited to a maximum frequency deviation of 25 kc. Since the frequency deviation is proportional to the amplitude of the modulating signal, it is evident that the modulating signal may not be greater than a certain amplitude. This amplitude can readily be ascertained by the Bessel zero method.

First, it is necessary to find the modulating frequency that produces a modulation index of 2.405 when the frequency deviation is 25 kc. An audio signal of this frequency should then be applied to the FM transmitter and increased in amplitude until the carrier is completely suppressed, as evidenced by the disappearance of the carrier beat note in the receiver. At this point, the modulation index is 2.405 and the corresponding frequency deviation is given by the formula: $F_d = 2.405\ F_m$. This relation, solved for F_m, will indicate the audio frequency to be employed. For example, if the maximum frequency deviation is to be 25 kc, then, $F_m = F_d/m = 25/2.405 = 10.395$ kc.

(*c*) TEST PROCEDURE.—After finding the above quantity, proceed with the steps listed below:

1. Set the audio oscillator to 10.395 kc.

2. Apply this signal to the audio amplifier of the transmitter. It is assumed that the amplifier is coupled to the modulating stage of the transmitter.

3. While listening attentively to the beat note produced by the carrier component of the FM transmission, steadily increase the amplitude of the audio signal. When the beat note disappears completely, a frequency deviation of 25 kc has been reached. This indicates then, that the corresponding amplitude of the modulating signal must never exceed this figure during the operation of the transmitter.

When a large frequency deviation, such as 75 kc is to be established, the process is a little more involved. Repeating the procedure of computation used previously, it is found that $F_m=75/2.405=31.2$ kc. This frequency is, however, too high for the audio stages of the transmitter. There are two ways of overcoming this difficulty.

One means is to utilize the second value of the modulation index at which the carrier disappears. This value, which is 5.52, leads to the relationship $F_m=75/5.52=13.586$ kc. Such a frequency is within the audio bandpass of many FM transmitters, but not all.

(*d*) TEST PROCEDURE.—Assuming that 13.586 kc is not too high, proceed in the following manner:

1. Set the audio oscillator to 13.586 kc.

2. Apply the signal to the transmitter in the same way as before.

3. Steadily increase the audio signal until the carrier disappears, as indicated by the disappearance of the carrier-produced beat note. The first point of carrier disappearance corresponds to a relatively low frequently deviation.

4. Continue to increase the audio signal. When the carrier disappears for a second time, the frequency deviation of the transmitter is 75 kc.

If the audio frequency (13.586 kc) is too high, recourse is made to another method. This procedure makes use of the fact that a frequency multiplying stage increases both the center frequency and the frequency deviation by the same factor. For example, in a transmitter incorporating a reactance tube, the frequency generated by the oscillator might be increased eight times before application to the power-output stage. In such a transmitter, a frequency deviation of 9.375 kc at the oscillator corresponds to a frequency deviation of 75 kc. In order to utilize this property, a portion of the oscillator signal should be coupled to the receiver as indicated by the dotted lines shown in figure 3-33. The receiver, of course, must be tuned to the oscillator frequency. With this setup, it is necessary to find the amplitude of audio signal that produces a frequency deviation of 9.375 kc. The frequency of the modulating signal is determined by the relationship $F_m = 9.375/2.405 = 3.9$ kc.

(*e*) TEST PROCEDURE.—After determining the above quantity, proceed with the steps listed below:

1. Couple the receiver by means of a small pickup coil to the modulated-oscillator stage of the transmitter.

2. Tune the receiver to the oscillator frequency.

3. Set the audio oscillator to 3.9 kc.

4. Increase the amplitude of the audio signal until the carrier-produced beat note in the receiver disappears. This amplitude of signal corresponds to a frequency deviation of 75 kc.

(2) MONITORING METHODS.—Although of great help when special monitoring equipment is unavailable, the Bessel zero method cannot compete with the convenience afforded by the many frequency and modulation monitors used with prime equipments. In addition to determining the percentage of modulation, these elaborately designed instruments perform a number of other functions. Depending upon the instrument, these other functions may include monitoring the center frequency of transmission, monitoring the modulating signal, measuring distortion and noise, and determining the AM noise content. In contrast to the lengthy procedure of the Bessel zero method, monitoring equipments have meters and lamps that provide direct indications.

c. FIELD-STRENGTH MEASUREMENTS.—It is possible to utilize the grid-dip meter as a relative field-strength meter. Refer to paragraph 3-6.*e.* for a discussion concerning grid-dip meters. For the grid-dip meter to perform the measurement mentioned above, the plate voltage must be turned off, and a loop antenna must be connected to the coil terminals of the instrument. The appropriate plug-in coil is inserted, and the meter is tuned to the transmission. If the received signal is sufficiently strong, current flows in the grid-cathode circuit. The relative magnitude of the field is indicated by the amount of meter deflection.

(1) MEASUREMENT DATA. — Field strength is measured in volts per meter. Since most field intensities are very small, it is convenient to employ the terms millivolts or microvolts per meter. Thus, a 1-millivolt potential difference would exist between two points 1 meter apart in a 1-millivolt-per-meter field, assuming that the points lie in the direction of the greatest rate of potential change. Therefore, an antenna with an effective height of 5 meters which is subjected to a field intensity of 20 millivolts per meter would develop a 100-millivolt signal.

The efficiency of a transmitting antenna is usually stated in such terms as power gain and field gain. These terms are based on the field intensity produced by a half-wave antenna in free space, at a distance of one mile under conditions for which there are no reflected waves. Power gain is then defined as the ratio of the power required by a half-wave antenna to produce a particular field strength at a distance of one mile to the

power required by the antenna under test to produce the same power, or, in equation form:

$$\text{Power gain} = \frac{\text{power required with vertical half-wave antenna}}{\text{power required with antenna under test}}$$

This ratio is usually given in db.

Antenna field gain is defined as follows: The term "antenna field gain" of a high-frequency broadcast antenna means the ratio of the effective (free space) field intensity produced at one mile in the horizontal plane (vertical antenna radiating waves vertically polarized) expressed in millivolts per meter for 1 kilowatt antenna input power to the number 137.6. It is assumed in this definition that no waves are reflected from the earth or surrounding objects. Hence, the field gain of a multielement antenna expressed at a ratio is:

$$\text{Field gain} = \frac{\text{field intensity of antenna at 1 mile for 1-kw input}}{\text{137.6 millivolts per meter}}$$

Since power proportional to voltage squared, the relationship between field gain and power gain is expressed in the following equation:

$$\text{Field gain} = \sqrt{\text{power gain}}$$

Consequently, a power increase of four times is required in order to double the signal intensity. If it is possible to increase the field intensity by utilizing a multielement antenna rather than by increasing the power, then less expensive equipment can be employed and operating costs will be lower.

(2) SIMPLE METER APPLICATION.—Simple instruments intended specifically for the measurement of field intensity usually employ a crystal diode connected into a circuit like the one shown in figure 3-34. Note that it is equivalent to the grid circuit of figure 3-36. A whip antenna is often used as the pickup antenna. To increase the sensitivity, it is advisable to employ a microammeter as the indicating device. The use of plug-in coils extends the instrument operation over a wide frequency range.

(3) ADVANCED METER APPLICATION.—When greater sensitivity is necessary, a more elaborate field-strength meter is required. One technique is to employ a specially designed receiver which has at the input of its first i-f amplifier an attenuator calibrated in db. The output of the mixing stage must be exactly proportional to the r-f signal voltage present in the grid circuit, and this property must hold for input amplitudes up to at least 1 volt. Other requirements are an auxiliary r-f oscillator and an electronic voltmeter

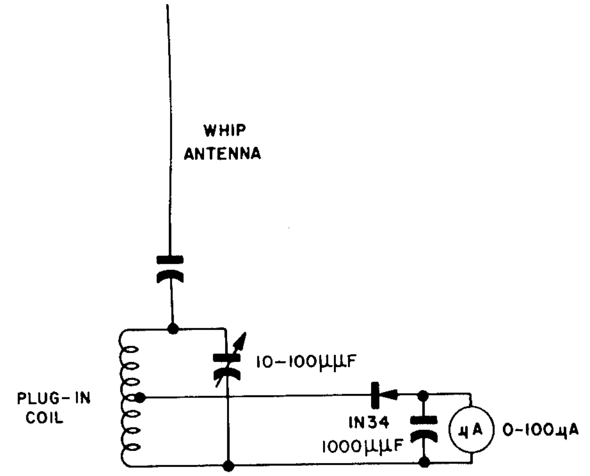


Figure 3-34. Circuit of Simple Field-Strength Meter

capable of reading about 1 volt. The oscillator need be only moderately well shielded.

When portability of the instrument is a consideration, the arrangement typified by a loop antenna shown in figure 3-35 is commonly used to develop the input r-f signal. The use of a loop antenna ordinarily leads to input arrangements like the circuit shown in the figure. The output of the auxiliary oscillator can be coupled to the loop by means of a transformer as shown, or applied directly across a resistor in series with the loop. The voltage transfer of the transformer is assumed to be a 1:1 ratio for the sake of simplicity. The local oscillator must be arranged and coupled to the input circuit so that its output is not varied as a result of tuning. Either the input circuit can be metered by an electronic voltmeter, or the plate circuit of the mixer can be metered by a milliammeter calibrated to indicate a 1-volt signal at the grid. A calibrated attenuator precedes the i-f amplifier. This placement of the attenuator avoids saturation of any of the i-f stages. Precaution must be taken to prevent overloading of the mixer stage. A detector incorporating a metering circuit follows the i-f amplifiers.

(*a*) TEST PROCEDURE.—The steps listed below describe a typical field-strength test:

1. Tune in the signal and adjust the attenuator to provide a convenient deflection of meter M2. Record this attenuator setting, which shall be referred to as A1.

2. Turn on the auxiliary oscillator, and set it to the frequency of the incoming signal.

3. Adjust the output of the auxiliary so that a preselected amplitude of signal, usually 1 volt, is indicated at the grid of the mixer.

4. Readjust the attenuator so as to make the deflection of meter M2 the same as that of step *1.* Record this attenuator setting, which shall be called A2.

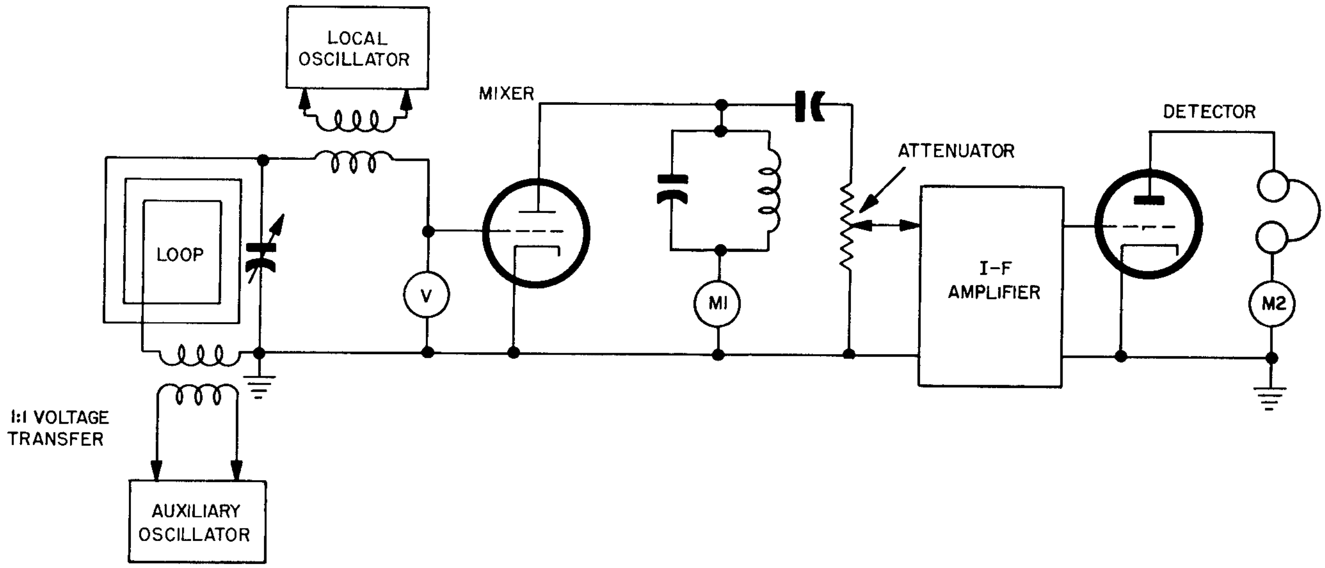


Figure 3-35. Circuit of Advanced Field-Strength Meter

Note

It would appear that the signal voltage induced in the loop is (A2 — A1) db below the oscillator voltage measured at the grid of the mixer. This is not quite true, since there is a resonant rise of voltage in the loop. As a matter of fact, r-f amplifying stages are sometimes placed between the loop and the mixer grid. It is convenient to refer to the ratio of the actual signal present at the grid of the mixer to the received loop signal voltage as the voltage transfer ratio. In order to make proper allowance for this ratio, the following additional steps should be performed.

5. Remove the auxiliary oscillator from the coupling transformer and connect it directly to the grid circuit. Do not change the output of the oscillator from the setting arrived at in step *3*.

6. Readjust the attenuator setting so that meter M2 again shows the same deflection as that obtained in step *1*. Call this attenuation A3.

7. Compute the quantity (2A2 — A1 — A3). The loop signal voltage is below the voltage measured in step *3* by this amount in db.

(*b*) ALTERNATE TEST PROCEDURE.—A more convenient method of measuring field strength is possible when a standard signal generator is available. A sensitive radio receiver is tuned to the signal—the loop antenna being adjusted for maximum reception. The gain of the receiver is set to provide a convenient deflection on a meter in the detector output circuit. Now the loop is oriented so that the received signal is eliminated. A voltage from the signal generator is then introduced into the antenna circuit, and its amplitude is adjusted so that the deflection of the meter in the detector circuit is the same as before. This amplitude divided by the voltage-transfer ratio is equal to the received signal.

d. AUDIO DISTORTION MEASUREMENTS.—The faithful reproduction of the audio components of a transmitted wave is achieved only when the over-all distortion is of a relatively low percentage. Although the FCC allows the harmonic distortion of a commercial AM transmission to be as high as 10 percent when the modulation level is 85 percent, the distortion produced by many transmitters is as low as 2 percent. Although very few receivers at present are in the extreme high-fidelity class, the majority of them will readily disclose poor quality in a transmission.

Modern transmitters use carefully balanced circuits extensively. In these balanced circuits, small changes in tube characteristics or values of critical parts can increase distortion intolerably. There are numerous devices available for measuring distortion, and, through proper testing and maintenance, it is possible to keep this distortion to a very low value.

Distortion is present to some degree in any audio amplifier, not merely in those associated with a transmitter or receiver. Consequently, the discussion to follow can be considered in a general sense to pertain to any audio amplifying system.

(1) ANALYSIS OF HARMONIC DISTORTION.—The distortion represented by a particular harmonic is simply the ratio of the harmonic to the fundamental frequency expressed as a percentage. Total harmonic distortion is expressed as the root-mean-square sum of all the harmonics

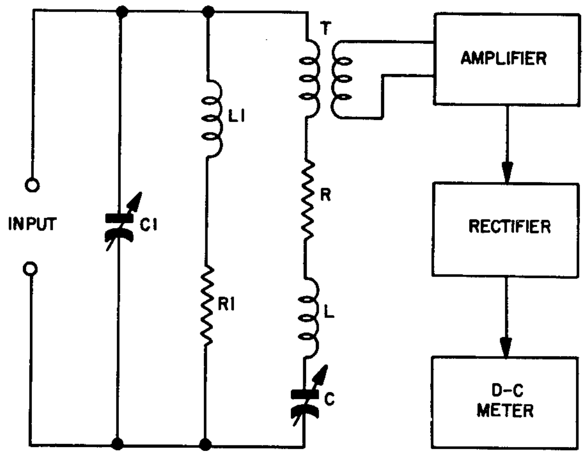


Figure 3-36. Block Diagram of Tuned-Circuit Type Harmonic Analyzer

present in the signal. If, for example, the second harmonic contributed 4 percent distortion, the third harmonic 6 percent, and the fourth harmonic 5.5 percent, the total would be as follows:

$$\sqrt{16 + 36 + 30.25} = \sqrt{82.25} = 9.07\%$$

The figure 9.07 percent represents the total r-m-s harmonic distortion.

Four general types of test equipments are used for the measurement of the harmonic distortion contained in a signal. They are the tuned circuit analyzer, the heterodyne analyzer, the dynamometer analyzer, and the fundamental-suppression analyzer. The discussion to follow provides a brief description of these instruments and sets forth some of the advantages and disadvantages involved in their applications.

(2) TUNED-CIRCUIT HARMONIC ANALYZER.—The harmonic content of a wave can be determined by a method which makes use of a tuned circuit as shown in figure 3-36. The series resonant circuit consisting of inductor L and capacitor C is tuned to a specific harmonic frequency. By means of transformer T, this harmonic component is applied to an amplifier. The output of the amplifier is rectified and used to actuate a d-c meter. After a reading is obtained, L and C are tuned to the next harmonic and another reading is taken. The parallel resonant circuit composed of L1, R1, and C1 provides compensation for the variation in the a-c resistance of the series circuit, and for the variation of the amplifier gain over the frequency range of the instrument. Consequently, the sensitivity of the equipment is nearly the same at all frequencies.

There are numerous modifications of the basic instrument just described. For example, equalizing networks are generally used in place of the compensating parallel resonant circuit. Frequently, the transformer is omitted and the amplifier is excited by the voltage across either L, C, or R. The usual choice is the inductor L, since the increase of its impedance with frequency offsets the usual decline in the amplitude of the higher harmonics.

There are two major disadvantages encountered in the tuned circuit method. One is the difficulty encountered at the lower frequencies, necessitating the use of large component values in the tuned circuit. The harmonics of the signal, moreover, are often so close in frequency that they cannot be distinctly separated. Various circuit refinements alleviate this difficulty. In many instances, it is inconvenient to measure each component harmonic individually instead of taking a single reading for the total harmonic distortion. Lastly, the variation of the tuned-circuit impedance with changing frequency is often a troublesome problem.

(3) HETERODYNE HARMONIC ANALYZER.—In the heterodyne type of analyzer, which is widely used, the difficulties of the tuned-circuit method are avoided by the use of a highly selective, fixed-frequency filter. The output of a variable-frequency oscillator is heterodyned successively with each harmonic of the input signal, and either the sum or difference frequency is made equal to the frequency of the filter. As a result of converting each harmonic to a constant frequency, it is possible to use extremely selective filters, often of the quartz-crystal type. With the utilization of these filters, only the constant-frequency signal corresponding to the particular harmonic under test is passed. The frequency of the filter must be higher than the highest harmonic to be measured.

Figure 3-37 shows in block-diagram form the essentials of a heterodyne type of harmonic analyzer. A balanced modulator is commonly employed as the mixing device, since it offers a simple means of lessening the amplitude of undesired components which would otherwise cause errors

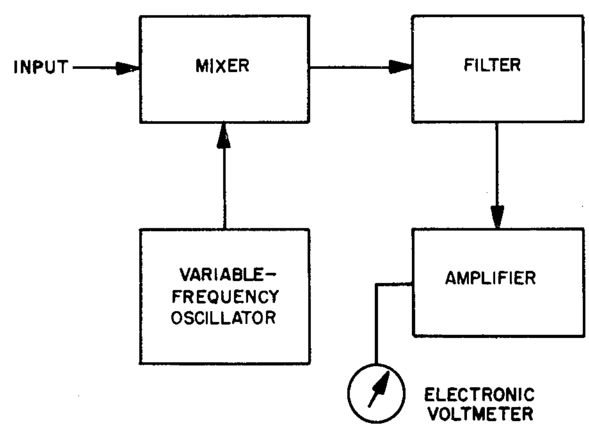


Figure 3-37. Block Diagram of Heterodyne Type Harmonic Analyzer

in the measurement. Another advantage is the low harmonic distortion generated by a balanced modulator as compared to other types of mixers. In addition to quartz-crystal filters, inverse-feedback filters also achieve excellent selectivity. A balanced electronic voltmeter generally serves as the indicating device. Some heterodyne analyzers are calibrated to provide direct readings, and in others the harmonics of the impressed signal are compared with a reference voltage, usually by making the latter equal to the amplitude of the harmonic.

(4) DYNAMOMETER-TYPE ANALYZER. —Briefly, a dynamometer is a device which compares the magnetic force between one moving coil and at least two stationary coils. Refer to paragraph 2-2.a.(2) for a more detailed description of this instrument.

The dynamometer principle has been adapted to analyzing waveforms of rather low frequencies. The complex wave, after suitable amplification, is applied to one fixed coil of the dynamometer, and the output of a variable-frequency (search) oscillator is applied to the other. When the frequency of the search oscillator is extremely close to a harmonic of the waveform under test, the moving coil and the indicator attached to it oscillate at the difference frequency. The maximum deflection is proportional to the product of the currents in the two coils, that is, to the oscillator current and to the harmonic component. By holding the oscillator current constant with the aid of a meter, the deflection of the pointer can be made proportional to the harmonic alone. A wave is analyzed, therefore, by varying the frequency of the search oscillator and noting both the frequency at which the beats occur and the amplitude of the deflection. Dynamometer analyzers can also be designed to give steady deflection. Instruments of this type, however, are extremely limited in usefulness. One restriction is the inability to analyze frequencies above approximately 3 kc. Another problem is the difficulty in keeping the oscillator signal exactly in phase with the waveform under test.

(5) FUNDAMENTAL-SUPPRESSION ANALYZER.—If the principal consideration is the total harmonic distortion, rather than knowledge of individual components, the fundamental-suppression method of measuring distortion is used. In this method, the input waveform is applied to a network that suppresses the fundamental component and passes the harmonic frequencies with negligible attenuation. If a thermocouple or a square-law electronic voltmeter serves as the indicating device, the r-m-s value of all the harmonic components will be indicated.

There are a number of methods used for removing the fundamental frequency. One method utilizes a high-pass filter, which attenuates the fundamental drastically, but passes the harmonic

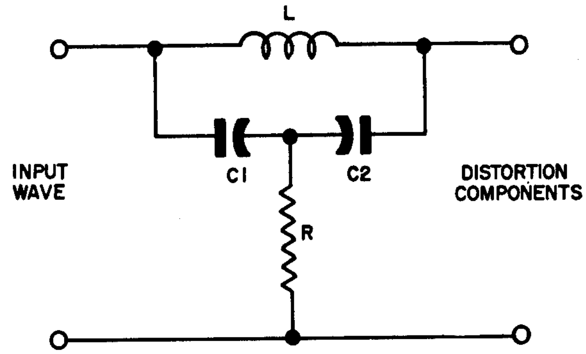


Figure 3-38. Bridged-T Type Suppression Network

frequencies. It is also possible to employ some kind of bridge circuit, for example, some form of the Belfils bridge. If the resonant circuit of the bridge is tuned to the fundamental frequency, a meter placed across the null points will indicate the r-m-s value of the harmonics. Another alternative is a bridged-T circuit similar to the one shown in figure 3-38. In this network, the resonant circuit consisting of inductor L and capacitor(s) C is tuned to the fundamental frequency, and resistor R is adjusted until the fundamental frequency is suppressed. The figure of merit (Q) of the resonant circuit must be at least from 3 to 5.

Figure 3-39 shows in block diagram form a basic fundamental-suppression distortion meter. The first reading is obtained by placing the switch in position 1 and adjusting the network for minimum output. At this setting, the fundamental frequency is suppressed. Next, the switch is placed in position 2 and the attenuator is adjusted until the output indication is the same as before. The attenuator reading in db then gives the amount of r-m-s distortion below the amplitude of the fundamental.

Distortion meters which operate on the principle of fundamental suppression are simpler and

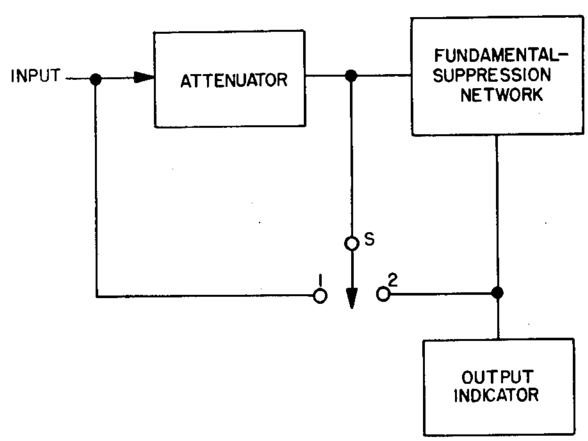


Figure 3-39. Block Diagram of Fundamental-Suppression Analyzer

less expressive than instruments of the heterodyne type, but cannot be used when the amplitudes of the individual distortion components must be known. However, a network that suppresses the fundamental can be used to advantage in combination with other types of analyzers, such as tuned-circuit and heterodyne meters. Two benefits are gained; one is a reduction in the amount of harmonic distortion generated in the analyzer itself, and the other is less-stringent selectivity requirements. This is important when there is frequency drift of the waveform being analyzed. Finally, wave analysis can be accomplished quite accurately by means of an oscilloscope in conjunction with graphical methods, if the fundamental is removed first.

(6) INTERMODULATION DISTORTION MEASUREMENT.—The quality of an audio reproduction may prove unsatisfactory even when the harmonic distortion of a single frequency is low. This condition is frequently attributable to a beating effect between the various frequency components of the waveform, so that appreciable sum and difference-frequency components are produced. Since the new frequencies are not harmonically related to the original frequencies, their presence is especially objectionable.

Intermodulation can be determined by simultaneously applying to the amplifier under test two sine waves of different frequencies (for example, 400 cps and 1500 cps), and then measuring the amplitude of the difference-frequency component (1100 cps) appearing in the output. By means of a suitable filter, all signals but the 1100 cps component must be suppressed. The remaining component may then be rectified and applied to a d-c meter. Intermodulation percentages under 8 or 10 percent are considered good. Instead of confining the test to the amplifier alone, it is an easy matter to apply the two signals to the input of an entire audio recording and reproducing system. Intermodulation distortion in this case is an index of the over-all quality of the system.

(7) PHASE DISTORTION — SQUARE-WAVE TESTING.—Another important reason for unsatisfactory reproduction despite low harmonic distortion is poor phase response. Phase distortion is especially injurious to sounds of a sudden or transient nature, usually referred to as impulse sounds. Valuable information concerning phase distortion can be quickly learned from square-wave tests. For a discussion of square-wave testing and interpretation of wave patterns refer to paragraph 2-11.*a.*(3) (*a*) and figure 2-67.

e. GRID-DIP METER APPLICATIONS.—Stated in simple terms, a grid-dip meter is a multiple-range oscillator which includes a meter in its grid circuit to indicate current flow. When an external circuit absorbs energy from the tuned circuit of the oscillator, the grid circuit receives less excitation and consequently less grid current flows. This action produces a distinct dip in the meter indication. Figure 3-40 shows a representative circuit of this meter. The use of plug-in coils results in extensive frequency coverage.

(1) METER CIRCUIT ANALYSIS. — The oscillator shown in the figure mentioned above is

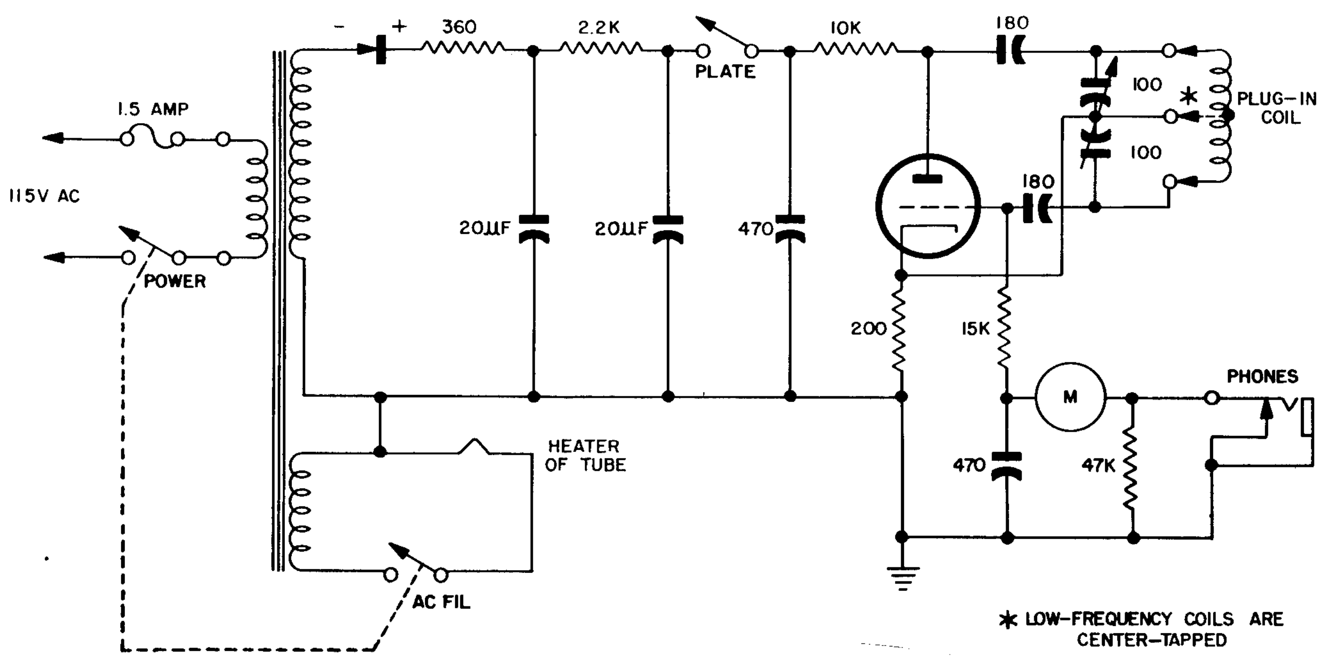


Figure 3-40. Typical Grid-Dip Meter Circuit

a conventional Colpitts type. The low-frequency plug-in coils, however, are center-tapped to preserve inductive balance irrespective of tuning. This, in turn, tends to stabilize the oscillations at a constant amplitude throughout the frequency band of the coil. Self-bias is employed to prevent excessive tube current when a plug-in coil is not in use. Since the meter is a part of the d-c path to ground, it indicates the flow of grid current. A selenium rectifier and filtering circuits are included to furnish d-c plate voltage for the oscillator. This voltage is applied by means of a separate switch. When the switch is in the off position, thereby de-energizing the oscillator, the grid-cathode portion of the tube can function as a diode detector.

(2) CHECKING TUNED CIRCUITS.—One application most frequently associated with the grid-dip meter is that of determining the resonant frequency of a tuned circuit while that circuit is de-energized. In this use, the switch which applies the d-c voltage to the plate must be closed. Then the plug-in coil which simulates a probe is brought physically near the tuned circuit under test and oriented so that an energy transfer can be effected. Next, the frequency of the meter is slowly changed until a dip in the meter indication occurs. Since a dip indicates that energy is being absorbed from the tank of the oscillator by the external circuit, the resonant frequency of the external circuit and the frequency of oscillation must be the same. Thus, the foregoing procedure provides an exceptionally convenient method of checking or adjusting tuned circuits.

(3) OTHER APPLICATIONS. — Although less well-known than the preceding application, there are three other basic ways of using the grid-dip meter. It can be employed as a signal generator unless special shielding or a known amount of r-f voltage is required. Secondly, the instrument can serve as an oscillating detector for determining the fundamental or harmonic frequencies of energized r-f circuits. This technique calls for the connection of headphones into the grid circuit of the oscillator by means of the phone jack. When a source of r-f power is coupled to the probe, there will be an audible beat note in the phones each time the adjustable frequency of the test instrument is made nearly equal to the fundamental or a harmonic frequency of the r-f source. At zero beat, the setting of the calibrated dial specifies the frequency. Thirdly, a grid-dip meter can be operated as an absorption-type frequency meter. In this application, no plate potential is applied and the grid-cathode portion of the tube acts as a diode. Consistent with the behavior of a conventional wavemeter, the meter reading will increase perceptibly when the instrument is closely coupled and tuned to a source of r-f energy.

(4) MISCELLANEOUS USES. — Because of the many different ways it is possible to operate the grid-dip meter, it has quite a large number of applications of which some of the more common shall now be mentioned. The equipment can be used to align superheterodyne receivers and to determine whether the local oscillator is functioning. It can be used to tune the tank circuits of a transmitter and to neutralize any of the stages. A grid-dip meter can detect a parasitic oscillation and determine its frequency. Both shunt and series traps can be adjusted by means of this versatile test instrument. Various antenna and transmission-line adjustments can also be made. The device sometimes is used to measure electrical quantities, such as the figure of merit, Q, inductance, and capacitance. Despite its lack of sensitivity, it is occasionally used as a relative field-strength meter. Test procedures for the various applications mentioned above are usually given in instructive literature which accompanies these equipments.

3-7. RADAR TESTING—GENERAL.

It is possible to determine to some degree the satisfactory operation of a radio receiver by listening to its tone and observing how much the gain control must be advanced to obtain sufficient volume. However, unlike most radio communication equipments, radar systems cannot be tested by observation alone to determine whether the performance is satisfactory.

In the field of radar, reliance alone on visual observation to judge the range capability and data accuracy of radar systems has been found to be so inaccurate as to be completely valueless. Numerous tests made on radar equipments in the field strongly emphasize this fact. In one instance, the performance of approximately 100 different systems was carefully measured with test equipment of known accuracy. In each case, the system under test was considered to be in normal operating condition by the radar personnel concerned. The results of these tests revealed that on the average the maximum effective range of the radar equipments under test was only one half the maximum range possible, had the equipments been operating at peak efficiency. In fact, five radar sets were found to be operating at less than 10 percent of their possible maximum range, which means in effect, that these radars were protecting only 1 percent of their assigned tactical areas. Since such poor performance as demonstrated by these tests may have serious war-time consequences, it should readily be seen that performance testing is of the utmost importance in radar work.

Investigation of the cause of this unsatisfactory situation showed that many technicians are not sufficiently familiar with the techniques and procedures necessary to test microwave-radar systems properly. In the text to follow under the gen-

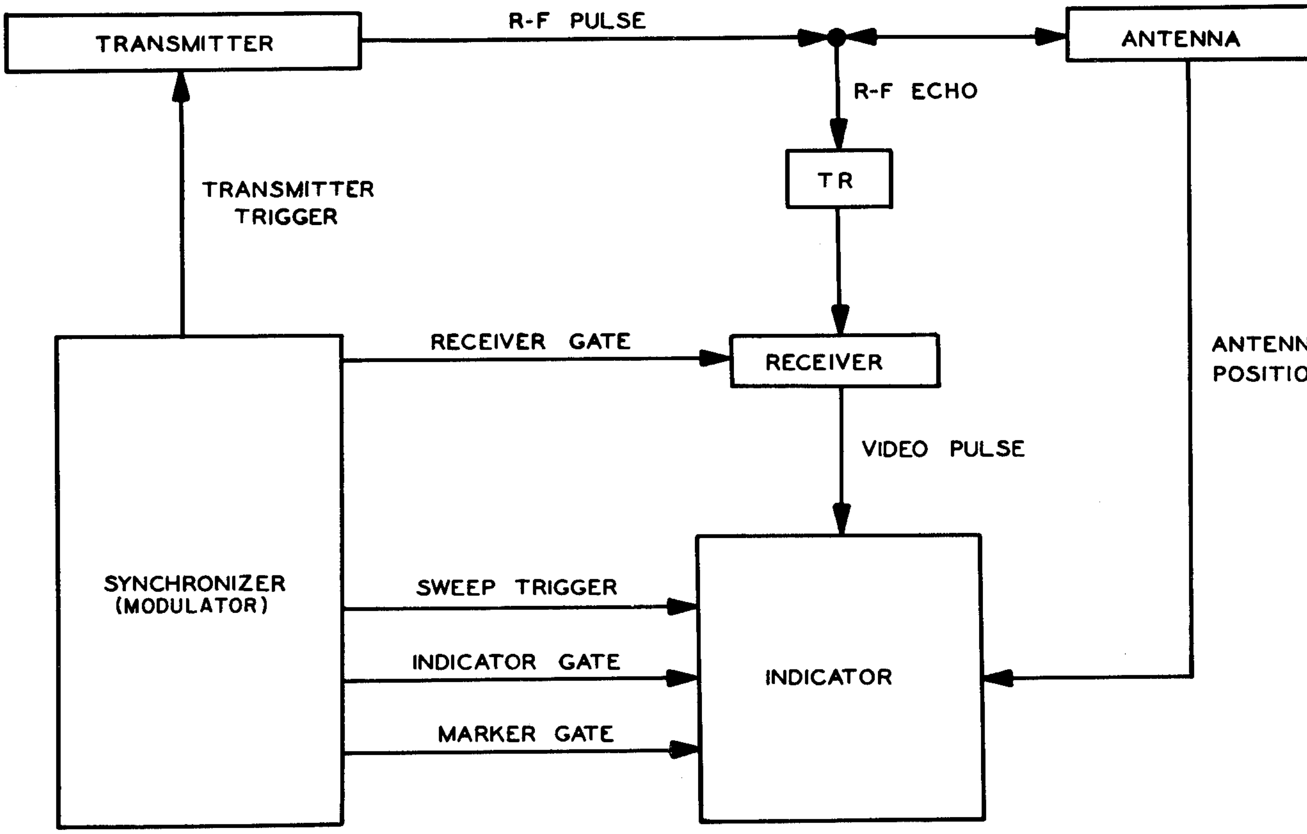


Figure 3-41. Block Diagram of Typical Radar System, Showing Timing Data Supplied by the Synchronizer

eral title of RADAR TESTING, an effort is made to remedy this situation. It is assumed that the reader is already familiar with the basic principles of radar. However, by way of review, a brief discussion of the functional requirements of the range-determining components of a radar system is included below.

a. RADAR SYSTEM FUNDAMENTALS.—This discussion briefly describes the operational requirements of the components of typical radar systems. For purposes of study, the typical radar system can be reduced into the following functional components: synchronizer (modulator), transmitter, antenna, receiver, and indicator. Because power supplies differ so greatly between different radar sets, they will not be considered in this general discussion. While the complexity of each of the above components may vary considerably, depending on the use for which the particular radar equipment was designed (i.e., search, navigation, fire control, etc), basically the function of each type of unit is identical in all radars. It is not the purpose of this discussion to describe any specific radar set, but rather to deal with the functional requirements of each unit necessary for the efficient over-all performance of any radar system.

(1) SYNCHRONIZER.—Figure 3-41 illustrates the typical timing requirements of a radar system which are developed and supplied by the synchronizing component. The timing circuits may all be located in one unit, or as is often the case, they may be distributed throughout one or more additional components, such as, the transmitter, indicator, or receiver. In externally synchronized systems, a trigger pulse is fed to the transmitter for the purpose of timing the firing of the r-f oscillator with the rest of the system. In some sets, a gate pulse is also fed to the receiver in order to turn it on immediately after the transmitter fires.

When the r-f performance of the transmitter and receiver is measured, some of the test equipments that are used must be synchronized with the system. To supply the necessary timing signal, test receptacles are usually conveniently located on these units to provide sync voltage of the proper amplitude and polarity.

(2) TRANSMITTER.—The transmitter consists of an r-f generator and a modulator, or pulsing system. In microwave systems, the generator is usually a magnetron, because of its relatively high output power, whereas in lower-frequency systems a ring or conventional type oscillator is used. For satisfactory operation, a nearly rectangular modulator pulse is required. A pulse with a flat top is desired because a magne-

tron will tend to shift frequency if its high voltage (furnished by the modulating pulse) varies during the period of oscillation. A steep leading edge is also required, particularly in fire-control systems, where accurate range data is necessary. In systems where minimum-range data is needed a pulse with a steep trailing edge is essential.

The required width, or duration, of the pulse also depends upon the type of radar system in which it is to be used. In the case of long range air-search systems, wide pulses (2 to 20 microseconds) are utilized in order to maintain a high average of transmitted power. For surface-search and fire-control equipments, which require high resolution, narrow pulses (.1 to 2 microseconds) are used.

Any sizable variation from normal in pulse width, shape, or amplitude seriously affects the range capability and accuracy of the system. These changes would not be apparent to a radar operator. For this reason, test methods and procedures have been devised to observe and measure the over-all performance of a radar system, and are now part of the preventive maintenance schedule.

(3) ANTENNA.—A typical antenna system consists of such components as the transmission or r-f lines, with associated accessories such as rotating joints, duplexer, slotted-line section and directional coupler, and the antenna and antenna reflector, some of which are shown in figure 3-42. Although the r-f lines may be either coaxial cable or wave guides, their function is the same, namely, to deliver the maximum amount of power from the transmitter to the antenna, consistent with good frequency stability. Many factors tend to reduce the efficiency of r-f lines. Improper coupling, faulty rotating joints, dents in the line, or poor solder joints may produce an impedance mismatch between the r-f lines and the antenna or transmitter, resulting in a high standing-wave ratio, magnetron instability, and a reduction in system performance.

Since radar systems both transmit and receive through the same antenna, some method must be employed to block the receiver during transmitting time. The most common device used is the duplexer, consisting of a transmit-receive (TR) switch, and usually an anti-transmit-receive (ATR) switch. The TR switch is a gas-filled tube which is designed to short circuit across its spark gap, each time the transmitter fires, thus preventing saturation of the receiver and damage to the crystal mixer (when used) by a strong signal.

To prevent loss of the return signal in the transmitter during receiving time, many systems incorporate an ATR switch, located an odd number of quarter-wave-lengths from the receiver T-junction. During transmission, both the TR and ATR gaps are fired, producing short circuits at these points. Thus the transmitter power is conducted

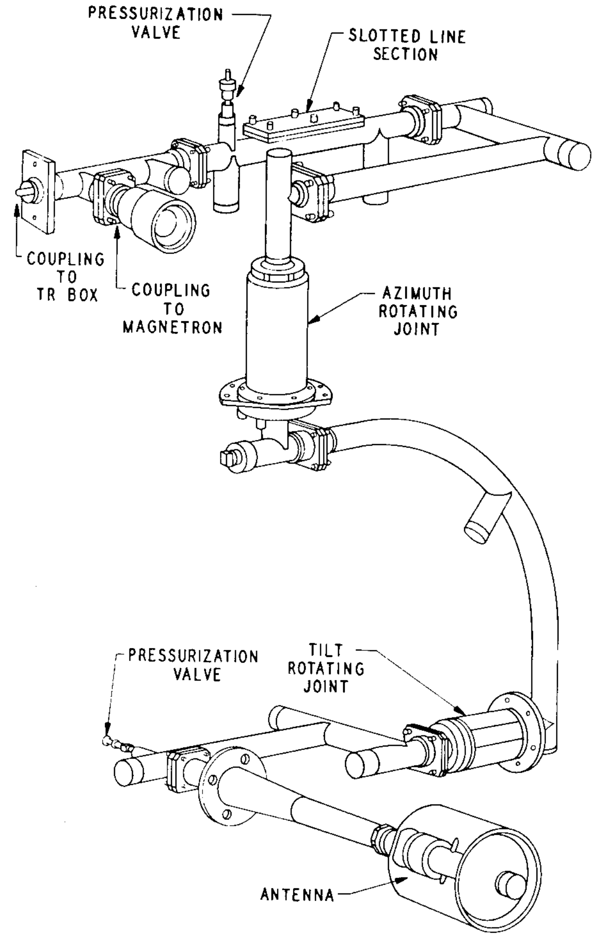


Figure 3-42. Typical Microwave Antenna System

to the antenna without loss. During reception neither is fired, and the impedance relations of the ATR switch are such that the received echo is reflected into the receiver with minimum loss. In addition to this, the TR and ATR switches must be capable of recovering quickly after firing of the transmitter, so that echoes from nearby targets may be received. Recovery time of TR tubes ranges from 3 to 20 microseconds. Fire-control radars require tubes with the most rapid recovery time, whereas search systems employ tubes with longer recovery periods. Since the recovery time of these tubes tends to increase with use, it must be checked periodically to ensure proper operation of the radar system. Methods of measuring recovery will be discussed later.

Early radar antennas often require considerable adjustment for efficient operation, but most present-day antennas are preset at the factory, and require no further adjustments in the field. However, when making r-f tests or measurements, it is important to position the antenna so that it will not be affected by strong echoes from nearby fixed targets.

To provide efficient r-f test points, two devices, directional couplers and slotted-line sections, are

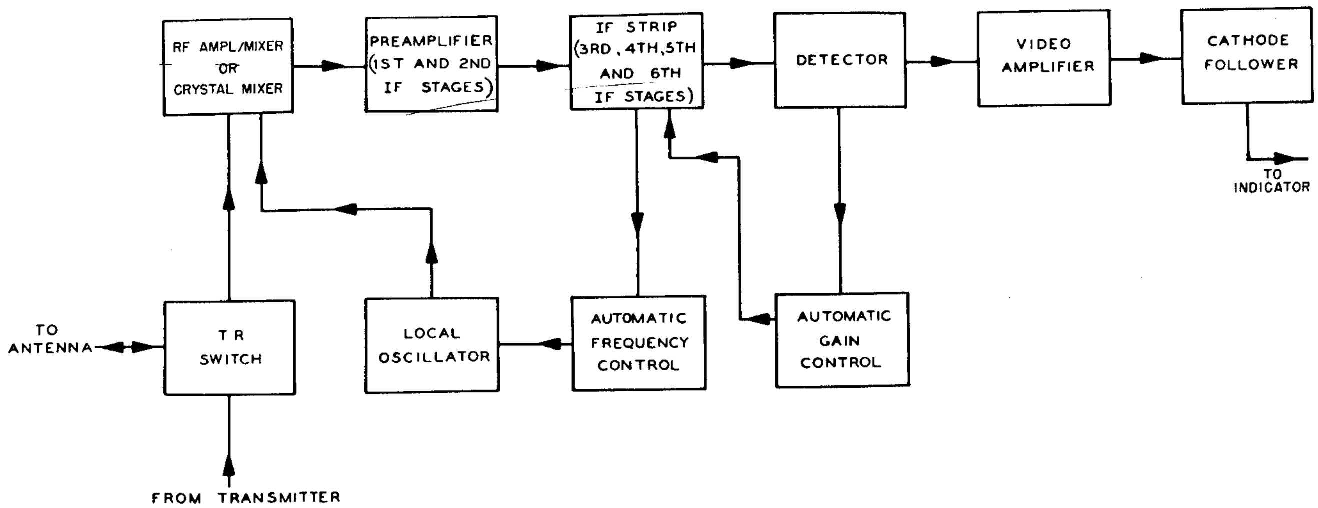


Figure 3-43. Block Diagram of a Microwave Receiver

used. In some equipments these devices are permanently built into the antenna system. In others they are included as part of the test equipment, and may be inserted in the r-f line whenever tests are to be made.

(4) RECEIVER.—An efficient receiver is one having good sensitivity, short recovery time, and sufficient bandwidth to pass a received pulse echo without undue distortion. Figure 3-43 shows the necessary stages required to obtain these results.

Because of the high frequencies at which most radar receivers operate, conventional r-f amplifiers are of limited use. The received signal is fed directly to a crystal mixer or r-f amplifier. The local-oscillator and preamplifier stages are normally located close to the mixer or r-f amplifier. A silicon crystal is usually used as a mixer because of its low noise level. Two i-f stages follow immediately, as a preamplifier; they prevent the i-f output signal from being lost, because of attenuation in the transmission line, before it reaches the remotely located receiver unit.

Although the TR switch partially protects the receiver each time the transmitter fires, a strong signal still may leak through directly from the transmitter. Unless additional precautions are taken, this signal may overdrive and block the receiver, rendering it insensitive to signals reflected from nearby targets. This blocking usually occurs in one of the resistance-coupled video stages. Several methods are used to minimize this undesirable effect, such as using a receiver gate pulse, or feeding a negative-going signal from the second detector to the first video stage.

The bandwidth requirements of the receiver also depend on the type of radar system in which it is used. Fire-control radars require broad-band receivers for accurate range data. Search systems, on the other hand, operate satisfactorily with narrow-band receivers, since merely the presence and approximate range of a target are usually all the data required.

(5) INDICATOR.—The indicator performs the important function of transforming the electrical information gathered by the radar into a visual presentation on the face of one or more cathode-ray tubes which are part of the component. If the system includes an "A" scope or a "PPI" scope, it can be used for visual observation of receiver performance and echo box "ring time," as will be explained later in the text.

It should be emphasized that while the display on the "A" scope may indicate, to the inexperienced operator, that all the components of a radar system are operating, it will not show how efficiently they are performing. The efficiency can be determined only by careful performance testing.

3-8. RADAR TESTING—FREQUENCY MEASUREMENTS.

The measurement of frequencies employed in radar operation falls into two general categories: transmitter frequency and receiver frequency.

For the transmitter operation of any given radar system, a range of frequencies is assigned for that system. Therefore, the transmitter must operate within this band of assigned frequencies, if normal operation is to be expected. Transmitter operation is restricted to a certain range of frequencies for the following reasons: First, radar beacon stations, which are assigned to each radar band, will respond only to signals within a given frequency range. Second, the associated waveguide tuning adjustments cover only a limited range of frequencies. Third, interference between radars used for different types of services could result if all radars were permitted to operate in the same band. For this reason, airborne S-band and ship-

board S-band radars usually operate in different parts of the band.

The testing of radar receiver frequency may consist of measuring the frequency at which the receiver operates most efficiently, or of measuring the local-oscillator frequency. For radar reception, a knowledge of the receiver frequency is not very important as long as the receiver is carefully tuned to the transmitter frequency. In receivers using afc, the local oscillator must, of course, be operated either above or below the signal frequency in accordance with the design specifications, but here again a knowledge of the exact frequency is not very important. However, in beacon reception, a knowledge of the exact receiver frequency is often necessary in order that the receiver may be accurately tuned (in the absence of a beacon signal) to the beacon-signal frequency, which is different from the transmitted radar-signal frequency. In beacon reception it is important that the receiver bandpass be centered about the frequency used for interrogating the beacon. The bandwidth of a beacon receiver is an important factor and should be checked along with the beacon receiver frequency. This measurement is often made with test equipment incorporated within the radar.

a. FREQUENCY TESTING COROLLARY DATA.—The text under this heading is included to provide the technician with information pertinent to the measurement of radar frequencies. The subjects discussed are: frequency testing standards, frequency coupling methods, test equipments commonly used in radar frequency testing, and the accuracy limitations of these instruments.

(1) FREQUENCY TESTING STANDARDS.—Equipments employed in frequency testing are classified as either primary or secondary standards. For a detailed discussion concerning frequency standards, refer to section 2, paragraph 2-7.*a.* To summarize in brief, a primary standard provides an extremely accurate source of frequencies which is checked against the rotation of the earth, and is used to calibrate secondary standards.

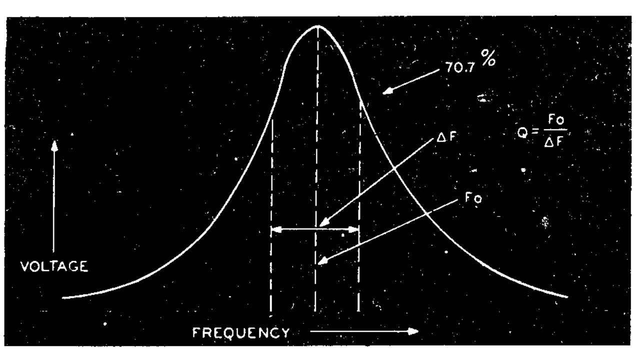


Figure 3-44. Response Curve of a Tuned Circuit

Secondary standards are dependent upon primary standards, but are not as cumbersome and difficult to use. Consequently, for radar maintenance, accurate test equipments comparable to secondary standards are used.

(2) FREQUENCY COUPLING METHODS.—Frequency testing instruments should never be coupled directly into the radar system, since the high-power transmitter pulse would develop very high voltage within resonant circuits associated with the instruments and arcing would result. Satisfactory methods of frequency coupling are provided by incorporating a frequency meter into the test setups described for power sampling techniques which are discussed in paragraph 3-9.*a.*(3).

(3) FREQUENCY TESTING EQUIPMENTS.—Two test equipments are satisfactorily used in the measurement of microwave frequencies. They are the resonant-coaxial-line frequency meter and the resonant-cavity frequency meter. Both of these test instruments depend upon a condition of resonance to provide an accurate test indication.

(*a*) TERMS ASSOCIATED WITH RESONANCE.—To provide a better understanding of the terms used in conjunction with resonant circuits, a brief discussion is given.

Figure 3-44 shows a typical curve of frequency plotted against voltage in a tuned circuit, with the resonant frequency designated by F_0. Bandwidth, or ΔF, is defined as the frequency spread between the two 70.7 percent voltage (half-power) points. The width of that portion of the curve considered flat is about one-tenth of the bandwidth, and is one of the factors that determine the accuracy of a frequency measurement. For example, if the bandwidth (ΔF) is 100 kc, then the accuracy is 10 kc.

The "Q", or figure of merit, of a tuned circuit is defined as the resonant frequency divided by the bandwidth; i.e., if the operating frequency is 3000 mc and the bandwidth is 100 kc, then the Q of the tuned circuit is 3000/0.1 or 30,000. It may be seen that the higher the Q, the less the bandwidth, and the greater the accuracy. In practice, the final accuracy is determined by the care used in the initial calibration of the frequency-testing equipment.

(*b*) RESONANT-COAXIAL-LINE FREQUENCY METER.—This type of frequency meter was discussed in section 2, paragraph 2-7.*d.*(1), and is illustrated in figure 2-42. To summarize in brief, coaxial-line frequency meters may be connected to operate as either transmission or reaction type indicators. When used as the transmission type, energy is fed into one coupling loop and the indicating device is connected to the other loop. When the circuit is resonant, the greatest energy transfer takes place and the indicator

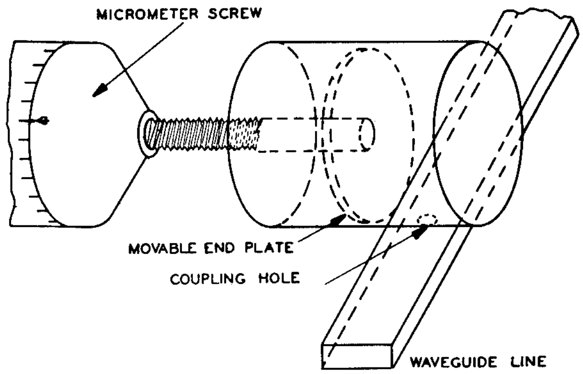


Figure 3-45. Partial Diagram of Resonant-Cavity Frequency Meter, Showing Method of Coupling

shows the greatest output signal. When used as the reaction type, the resonant circuit functions as an absorption device, so that at resonance the indicator shows a dip in the reading.

(c) RESONANT-CAVITY FREQUENCY METER.—Figure 3-45 shows a common type of resonant-cavity frequency meter, which consists essentially of a hollow metal cylinder coupled to a waveguide by means of a small hole or a coupling loop and coaxial connector. The cavity within the cylinder is resonant by virtue of its dimensions. The two end plates may be thought of as the capacitance elements, and the adjoining walls as the inductance. The frequency is varied by adjusting the position of one of the end plates with a micrometer screw, which is calibrated to indicate frequency. The accuracy obtained with this type of meter is better than that obtained with the resonant-coaxial-line frequency meter, also called "tuned echo box."

(4) FACTORS AFFECTING MEASUREMENT ACCURACY.—The accuracy of a microwave-frequency measurement is expressed in terms of maximum error in megacycles, and may be either absolute or relative. Absolute accuracy states how much error with respect to a standard (usually WWV) is involved in a single frequency measurement, whereas relative accuracy indicates how much error is involved in the difference in frequency (or increment) between two microwave signals. For example, assume a measurement accuracy of ±4 mc absolute and ±1 mc relative; if the frequency of a certain transmitter measures 9300 mc and the local oscillator frequency is 9330 mc, the following conclusions can be reached:

First, the transmitter frequency is somewhere between 9304 mc and 9296 mc (or 9300 mc ±4 mc absolute).

Second, the local-oscillator frequency is somewhere between 9334 mc and 9326 mc (or 9330 mc ±4 mc absolute).

Third, the local-oscillator frequency is 29 mc to 31 mc above the transmitter frequency (9330 mc minus 9300 mc or 30 mc ±1 mc relative).

Thus, it can be seen that the difference in frequency between two measured values is much more accurate than the measured values themselves.

In beacon-receiver frequency testing, an absolute accuracy of ±4 mc is not considered good enough. In order to obtain the required accuracy, manufacturers of frequency testing equipments carefully calibrate by hand that part of the test equipment which concerns beacon frequency testing, with the result that these equipments have an absolute beacon-frequency accuracy better than ±1 mc in the X band.

(a) DIAL BACKLASH.—Most of the early frequency meters were tuned by means of a micrometer screw, and the readings were converted into frequency with the aid of a calibration chart. Some of the newer type meters make use of a dial, geared to the screw, which indicates frequency directly. Thus dial readings are greatly simplified, but the gear mechanism associated with the dial introduces a certain amount of backlash, which affects the accuracy of the indication. The backlash effect may be minimized by always approaching the final dial setting from the same direction. This direction should be the same as was used during factory calibration, and should be specified in instructional literature accompanying the test equipment.

(b) ATMOSPHERIC CONDITIONS.—Atmospheric conditions such as temperature, relative humidity, and atmospheric pressure have an appreciable effect upon the accuracy of a frequency meter. This effect is minimized by constructing the resonant sections of materials that minimize or compensate for changes in temperature, and by hermetically sealing the units against moisture, with the result that sufficient accuracy is obtained for most applications. Where extreme accuracy is necessary, the correction charts for varying atmospheric conditions (supplied along with the equipment) must be used.

Atmospheric pressure variations, under normal conditions, are not great enough to require compensation; however, the effect of the reduced pressure at high altitudes may be appreciable. It should be emphasized that the conditions discussed above are the conditions existing inside the frequency meter rather than the conditions outside.

b. TRANSMITTER FREQUENCY TESTING.—Radar transmitters may be either fixed frequency or tunable. If the frequency of a fixed-frequency transmitter is measured and found outside the operating band, the magnetron or the defective component of the magnetron assembly is replaced. Tunable transmitters may be adjusted to any frequency within the operating band; this is a very desirable feature where several radars are in use in a limited area, because each one may be tuned to a different frequency to prevent interference.

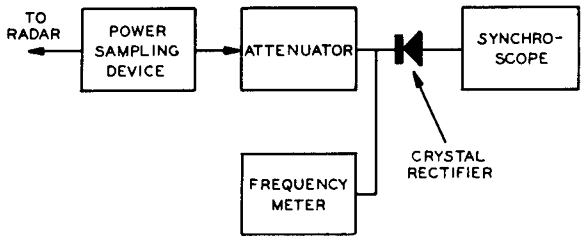


Figure 3-46. Test Setup for Reaction-Type Indication Method of Frequency Measurement

In addition, when jamming is present a different frequency may be free of the jamming signal. Since the operating bands are fairly wide, however, transmitter frequency tests do not require extreme accuracy.

(1) REACTION-TYPE INDICATION METHOD.—An early method of frequency measurement is shown in figure 3-46. This procedure utilizes the same test setup as the power-measurement method shown in figure 3-65, except for the addition of the frequency meter. The meter is connected to absorb power from the crystal detector at resonance; thus, a reaction type of indication is obtained. Figure 3-47 shows the appearance of the r-f envelope as the frequency-meter tuning is varied. Resonance is obtained when the center of the pulse reaches its lowest point, indicating maximum reaction. If desired, the synchroscope may

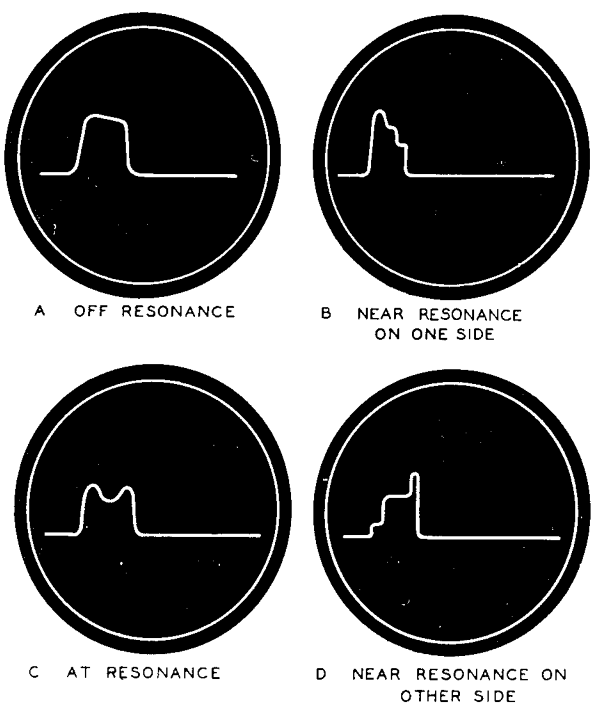


Figure 3-47. Waveform Changes Observed During Frequency Measurement

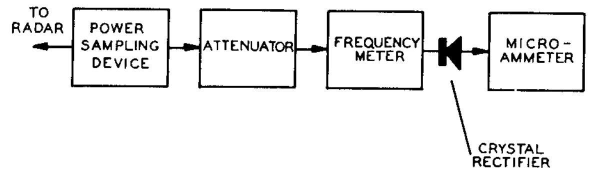


Figure 3-48. Test Setup for Transmission-Type Indication Method of Frequency Measurement

be replaced with a microammeter and the frequency meter adjusted for a dip in the current reading.

(2) TRANSMISSION-TYPE INDICATION METHOD.—Figure 3-48 shows a widely used test method for frequency measurement, in which the transmission type of indication is used.

(*a*) TEST PROCEDURE.—To perform the transmission-type indication method of frequency measurement, proceed as follows:

1. Connect equipment as shown in figure 3-48 and couple power sample into frequency meter.

2. Start with maximum attenuation and tune through range of frequency meter.

3. If no indication is observed, reduce attenuation about 10 db and tune through frequency range again. Repeat this process until a reading is observed.

4. Set frequency dial for maximum reading. Use sufficient attenuation to keep reading below full-scale value.

5. Read dial and convert reading to frequency.

Some frequency meters are provided with adjustable coupling loops instead of fixed loops, one of which is shown in figure 2-42. When making a frequency measurement using adjustable coupling, start with minimum coupling and increase the coupling until a reading is obtained. Where extreme accuracy is desired, it is good practice to note the maximum current reading and then detune for a 90-percent indication, first on one side of resonance, then on the other. The exact maximum reading will be halfway between the two 90-percent readings.

(3) COMBINATION POWER AND FREQUENCY TESTING.—In modern power testing equipment, a frequency meter is often included as an integral part of that equipment. The frequency meter is usually connected as shown in figure 3-49. For power testing, the frequency meter is tuned off resonance so as to have no effect on the accuracy of the power measurement. The test procedure given below is very simple and is usually performed directly after a power measurement.

(*a*) TEST PROCEDURE.—To measure frequency, perform the following steps:

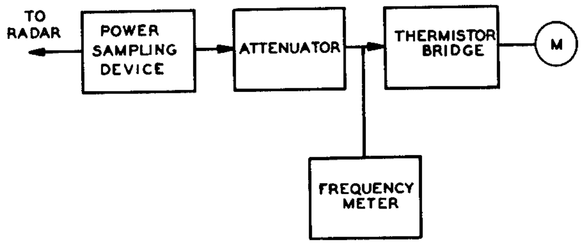


Figure 3-49. Test Setup for Combination Power and Frequency Measurement

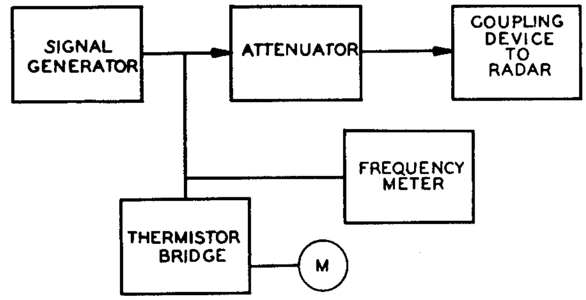


Figure 3-50. Test Setup for Receiver Frequency Measurement

1. Establish a 1 mw reading as discussed in the power testing procedure.

2. Tune the frequency meter for minimum meter reading. (Tune slowly or the resonance point may be passed before the thermistor can respond.)

3. Read dial and convert reading to frequency.

c. RECEIVER FREQUENCY TESTING.—Under normal conditions, the receiver is tuned to the transmitter frequency, and it is not necessary to make a receiver frequency test. However, for beacon operation, the receiver must be accurately tuned to a specified frequency and, in the absence of a beacon signal, the receiver frequency may have to be determined.

(1) TEST SETUP AND PROCEDURE.—Connect the test equipment as shown in figure 3-50 and proceed as follows for the measurement of receiver frequency:

(*a*) Tune the frequency of the signal generator to the receiver center frequency by observing the receiver output on either the radar indicator or a synchroscope. The resonant point will be indicated by maximum receiver output.

(*b*) Tune the frequency meter for zero beat with the signal generator. Zero beat will be indicated on the radar indicator or the synchroscope by a dip in output.

(*c*) Convert the frequency meter dial reading to frequency. This frequency will be the receiver center frequency.

(2) ALTERNATE TEST PROCEDURE.—In some cases, such as beacon operation, it may be necessary to set the frequency of the receiver to some predetermined value. To do this, use the setup in figure 3-50, and proceed as follows:

(*a*) Adjust the frequency meter to the desired frequency.

(*b*) Tune the signal generator for maximum dip as indicated on the thermistor bridge.

(*c*) Tune the receiver for maximum output on an output indicator. (A synchroscope may be connected to the receiver output to serve as an indicator.) The receiver is now tuned to the frequency established by the frequency meter.

(3) LOCAL-OSCILLATOR FREQUENCY MEASUREMENT. — The local-oscillator frequency can be measured by feeding the output of the local oscillator, directly if possible, to the frequency meter and making the test previously described. If desired, the local oscillator may be set to some predetermined frequency by setting the frequency meter above or below (as specified in instructional or maintenance literature) the frequency to be received by an amount equal to the intermediate frequency, and tuning the local oscillator for the required indication. This method is especially useful for a radar system employing afc, which requires that the local-oscillator frequency be set on a certain side of the signal frequency. For manually tuned radars, either side works well as far as receiver performance is concerned.

3-9. RADAR TESTING—POWER MEASUREMENTS.

In radar testing, it is often necessary to measure the power output of a radar transmitter, or to determine the output level of a signal generator so that the test equipment can be used to make accurate measurements on a receiver. It is important, threfore, that the technician have a thorough knowledge of the principles involved in the testing of power.

Modern testing methods require that the absolute power in watts be the unit of measurement. Power can be measured in terms of relative values, but for most purposes such measurements are considered unsatisfactory. For example, a crystal rectifier and d-c meter may be used to indicate power in units of meter deflection instead of watts. If periodic tests were made on a certain type of equipment, with the same crystal and meter, using the same procedure, any change in power would probably be discovered. (Any change indicates that corrective maintenance is needed.) However, this method has several faults: First, there is a danger that the initial reading, which must serve as a reference for comparison with later readings, may be taken at a time when the equipment is not

operating properly. Second, manufacturers' specifications are rated in watts, rather than in relative values. Third, the results of this method cannot be compared with the results obtained by another person or by means of other test methods. Fourth, a different crystal and meter combination would very likely give a different reading, so that if either the meter or crystal were damaged, the test procedures would have to be started all over again.

It is clear, therefore, that accurate, calibrated test standards must be used if maximum performance and maintenance efficiency are desired.

a. POWER TESTING COROLLARY DATA.— The text under this heading is included to provide the technician with basic information which is necessary to understand microwave power measurements and the techniques involved. The subjects covered are: pulse power and average pulse power, the decibel and its use, power sampling methods, attenuators, and a brief description of the thermistor.

(1) PULSE POWER AND AVERAGE PULSE POWER. — Power measurements are classified as either pulse power or average pulse power. The actual transmitter output occurs at peak level, but most modern test methods measure the heating value of the r-f energy, to obtain the average value. It is correct to use either value for reference so long as one or the other is consistently used. Frequently it is necessary to convert from pulse power to average pulse power, or vice versa; therefore the relationship between the two must be understood. Figure 3-51 shows the comparison between pulse power and average pulse power when a square pulse is used. The average value, which represents the actual heating value of the pulses, is located at a point somewhere between zero and peak. The level of the average value is defined as that level where the pulse area above average equals the area below average between pulses. If the pulses are evened off in such a way as to fill in the space between pulses, the level obtained is the average value, as shown in figure 3-51, where the shaded area of the pulse is used to fill in the space between pulses. In the

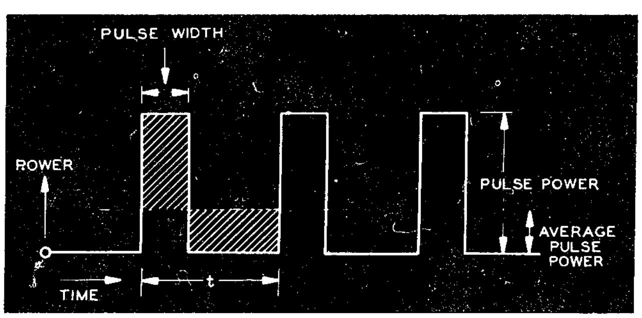


Figure 3-51. Transmitter Pulses, Showing Peak and Average Power

same figure, the area of the pulse is equal to pulse width multiplied by pulse power, and the area of the average value is equal to average pulse power multiplied by the pulse period (t). Since the two values are equal, it is permissible to express the equation as follows:

$$\text{Pulse width} \times \text{pulse power} = \text{average pulse power} \times t$$

Transposing terms in the equation produces:

$$\frac{\text{Average pulse power}}{\text{Pulse power}} = \frac{\text{Pulse width}}{t}$$

and since $t = 1/\text{PRF}$

Then

$$\frac{\text{Average pulse power}}{\text{Pulse power}} = \text{Pulse width} \times \text{PRF} = \text{Duty cycle}$$

The ratio of average pulse power to pulse power is called the "duty cycle," and represents the time the transmitter is on, each second. Duty cycle is simply a numerical value, and may be used to describe power, voltage, or current as long as the terms are consistent. For example, if a certain radar has a pulse width of ½ microsecond and a pulse recurrence frequency of 2000 pulses per second, the duty cycle is ½ $(10^{-6}) \times 2000$, or .001 (.1%). If the pulse power is 200 kw, the average pulse power is 200 kw $\times$ .001, or 200 watts. If the pulse current is 10 amp, then the average pulse current is .01 amp.

(2) THE DECIBEL AND ITS USE.—A brief discussion concerning the decibel will be found in paragraph 2-6.*a.*(2). The decibel is part of a larger unit called the bel. As originally used, the bel represented a power ratio of 10 to 1 between the strength of two sounds. To gain a better understanding of the bel, consider three sounds of unequal power intensity. If the power intensity of the second sound is 10 times the power intensity of the first, its power level is said to be 1 bel above that of the first. If the third sound has a power intensity which is 10 times that of the second, its level is 1 bel above that of the second. But, since the third sound is 100 times as intense as the first, its level is 2 bels above that of the first.

Thus a power ratio of 100 to 1 is represented by 2 bels; a power ratio of 1000 to 1, by 3 bels; a power ratio of 10,000 to 1, by 4 bels; etc. It is readily seen, therefore, that the concept of bels represents a logarithmic relationship, since the logarithm of 100 to the base 10 equals 2 (corresponding to 2 bels), the logarithm of 1000 equals 3 (corresponding to 3 bels), etc. The exact relationship is given by the formula:

$$\text{Bels} = \log 10 \frac{P2}{P1}$$

where $\left(\frac{P2}{P1}\right)$ represents the power ratio.

This logarithmic characteristic of the bel makes it a very convenient means for expressing power ratios. For example, assume that we desire to find the attenuation ratio of an r-f attenuator which is to be used to measure transmitter power output. On test, it is found that 60,000 watts of r-f input to the attenuator produces an output of 6 milliwatts. To find the attenuation ratio we use the equation:

$$\text{Attenuation ratio} = \frac{P2}{P1} = \frac{60{,}000}{.006} = 10{,}000{,}000$$

This ratio can be expressed much more conveniently in terms of bels.

$$\text{Bels} = \log \frac{P2}{P1} = \log \frac{60{,}000}{.006}$$
$$= \log 10{,}000{,}000 = 7 \text{ bels}$$

In this case, the attenuation ratio is 7 bels. In other words, P2 is said to be 7 bels up with respect to P1. In all instances where P2 is numerically greater than P1, as in the above example, the final result is expressed as a positive quantity. When P2 is smaller than P1, the numerical result is the same, but it is expressed as a negative quantity. If, for example, P2 is .006 watt and P1 is 60,000 watts, then:

$$\text{Bels} = \log \frac{P2}{P1} = \log \frac{.006}{60{,}000}$$
$$= \log .0000001 = -7 \text{ bels}$$

In this case, P2 is said to be 7 bels down with respect to P1.

Since the bel is a rather large unit, its use may prove inconvenient. Usually, therefore, a smaller unit, the decibel, is used. Ten decibels equal 1 bel. A 10-to-1 power ratio, which can be represented by 1 bel, can also be represented by 10 decibels (10 db), a 100-to-1 ratio (2 bels) can be represented by 20 db, a 1000-to-1 ratio (3 bels) by 30 db, etc. The previous formula for bels may be rewritten to give a result in decibels merely by multiplying by 10. Thus the formula becomes:

$$\text{Decibels (db)} = 10 \log \frac{P2}{P1}$$

It should be clearly understood that the term decibel does not in itself indicate power, but rather a ratio or comparison between two power values. In radar testing, however, it is often desirable to express performance measurements in decibels. This can be done by using a fixed power level as a reference. The original standard reference level was 6 milliwatts (.006 watt), but to simplify calculations a 1-milliwatt standard has been adopted and will be used hereafter in the part of this manual dealing with radar testing. (Note: A few equipments use one watt as a standard.)

When 1 mw is used as a reference level, the ratio is expressed in dbm's. The abbreviation "dbm" indicates decibels relative to a 1-milliwatt standard. Thus a pulsed radar transmitter having an average power output of 100 watts is said to have an average power output of 50 dbm. The conversion from power to dbm can be made as follows:

$$\text{Average power (dbm)} = 10 \log \frac{P2}{P1} = 10 \log \frac{100}{.001}$$
$$= 10 \log 100{,}000 = 50 \text{ dbm}$$

Conversions from power to dbm can be made more readily by means of the graphs shown in figures 3-52 and 3-53. If, as in the above example, the average power output is 100 watts, reference to the graph in figure 3-52 shows that the line representing 100 watts intersects the curve at point A, indicating that 100 watts is equivalent to 50 dbm.

Voltage and current ratios may also be expressed in terms of decibels, provided the resistance remains constant. For equal resistances, the formulas are:

$$\text{db} = 20 \log \frac{E2}{E1}$$
$$\text{db} = 20 \log \frac{I2}{I1}$$

The difference in the multiplying factor in these formulas (20 rather than 10, as in the case of power ratios) arises from the fact that power is proportional to voltage or current squared, and when a number is squared, the logarithm of that number is doubled. For power ratios, the db value is 10 times the logarithm of the ratio. For voltage or current ratios, the db value is 20 times the logarithm of the ratio.

As was stated previously, power measurements are classified as either pulse power or average pulse power. When testing the over-all performance of a radar system, it is necessary to know the pulse power output of the transmitter. However, modern test equipments can measure only the average power output, which, depending on the specific test equipment, may be given either in watts or in dbm. Therefore, the relationship between pulse power and average pulse power for a rectangular pulse must be determined. It is most convenient to express this relationship in terms of db.

The pulse power output of a transmitter in decibels relative to 1 mw can be found from the relationship:

$$\text{Pulse power (dbm)} = \text{average pulse power (dbm)} + \text{duty cycle (db)}$$

For a given radar transmitter, the two latter quantities are easily determined. The average pulse power output is measured by means of test equipment. If the value obtained from the test equipment is expressed in watts, it must be converted to dbm. The conversion can be made by

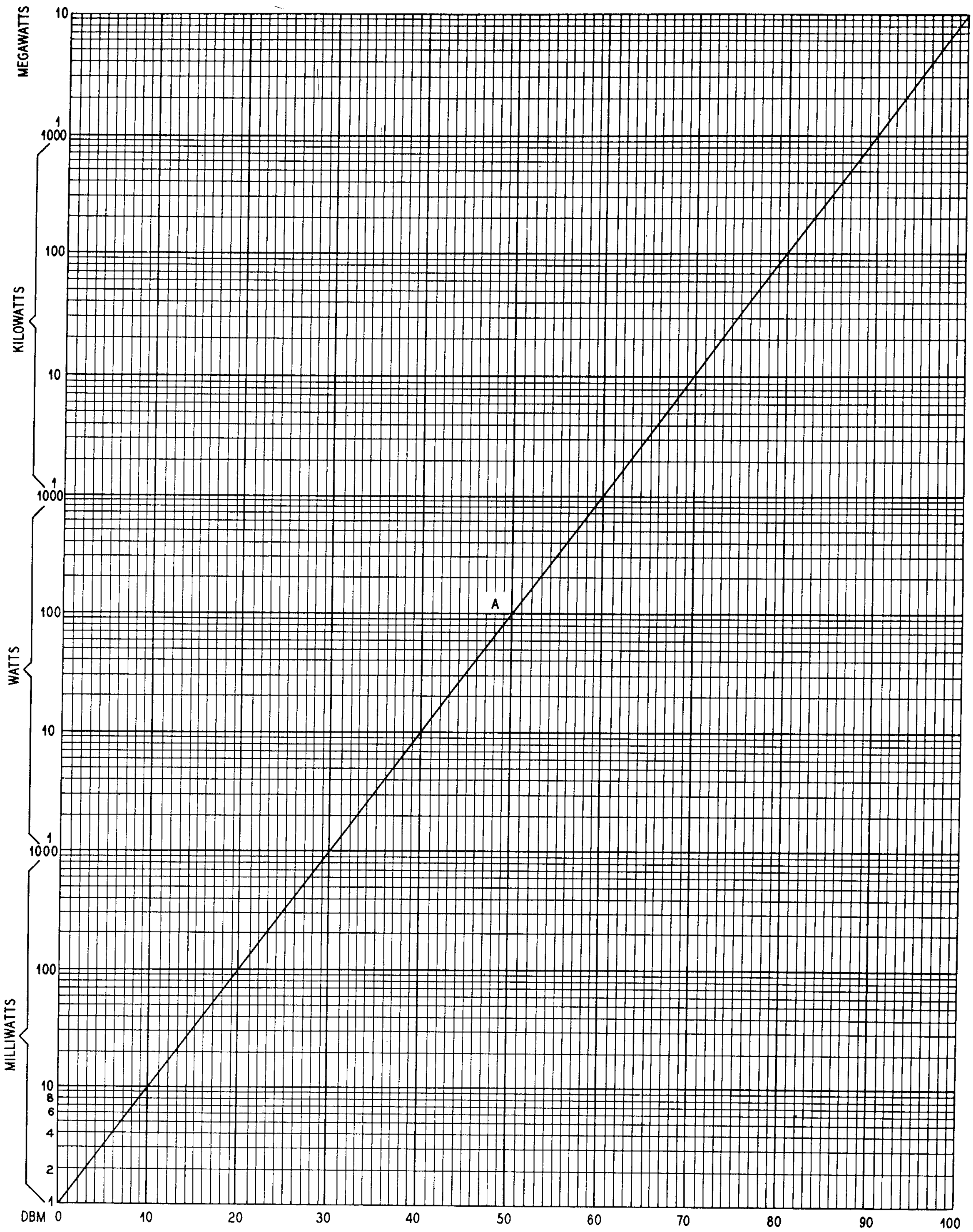


Figure 3-52. Power to DBM Conversion Chart—1 Milliwatt to 10 Megawatts

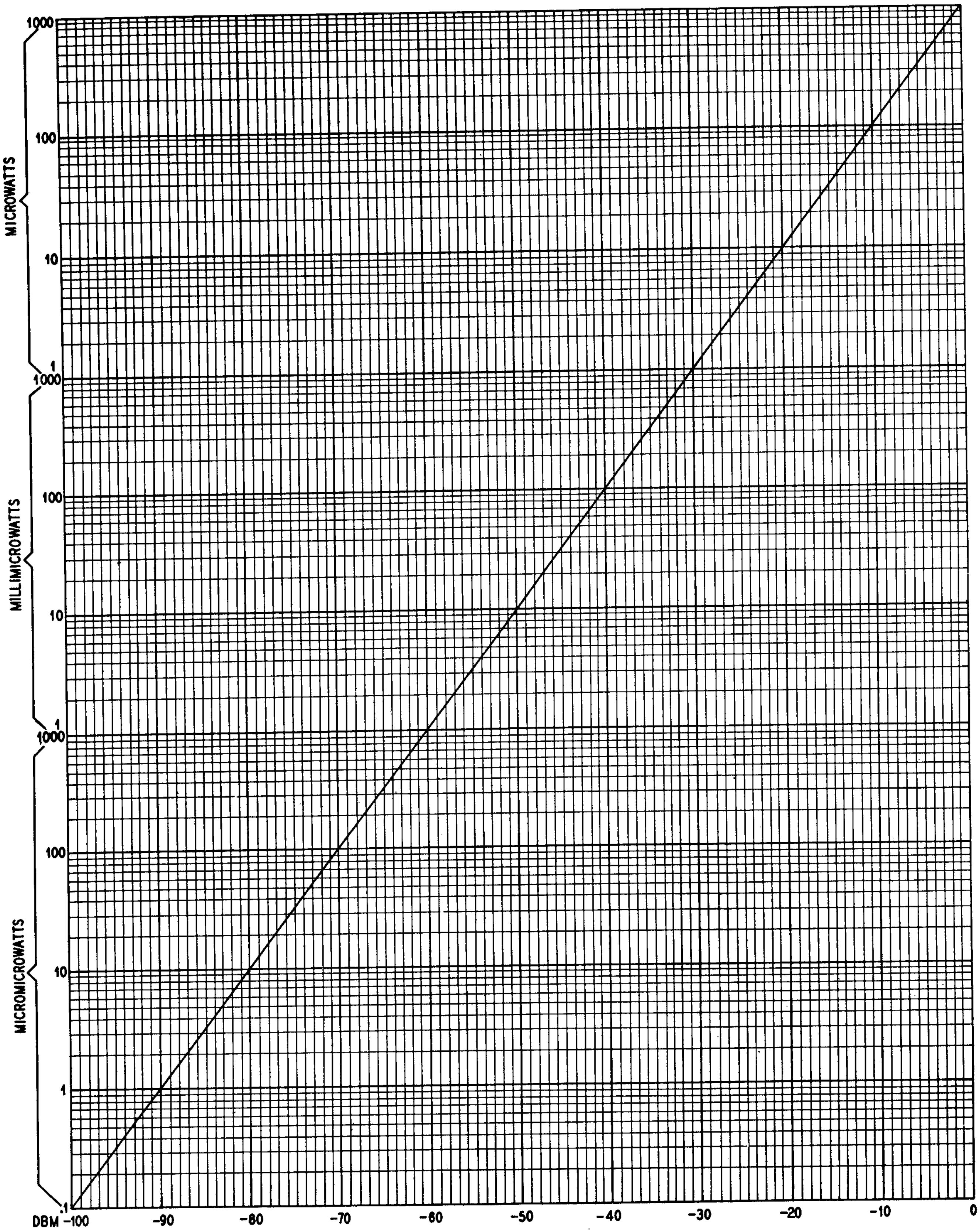


Figure 3-53. Power to DBM Conversion Chart—1 Milliwatt to .1 Micromicrowatt

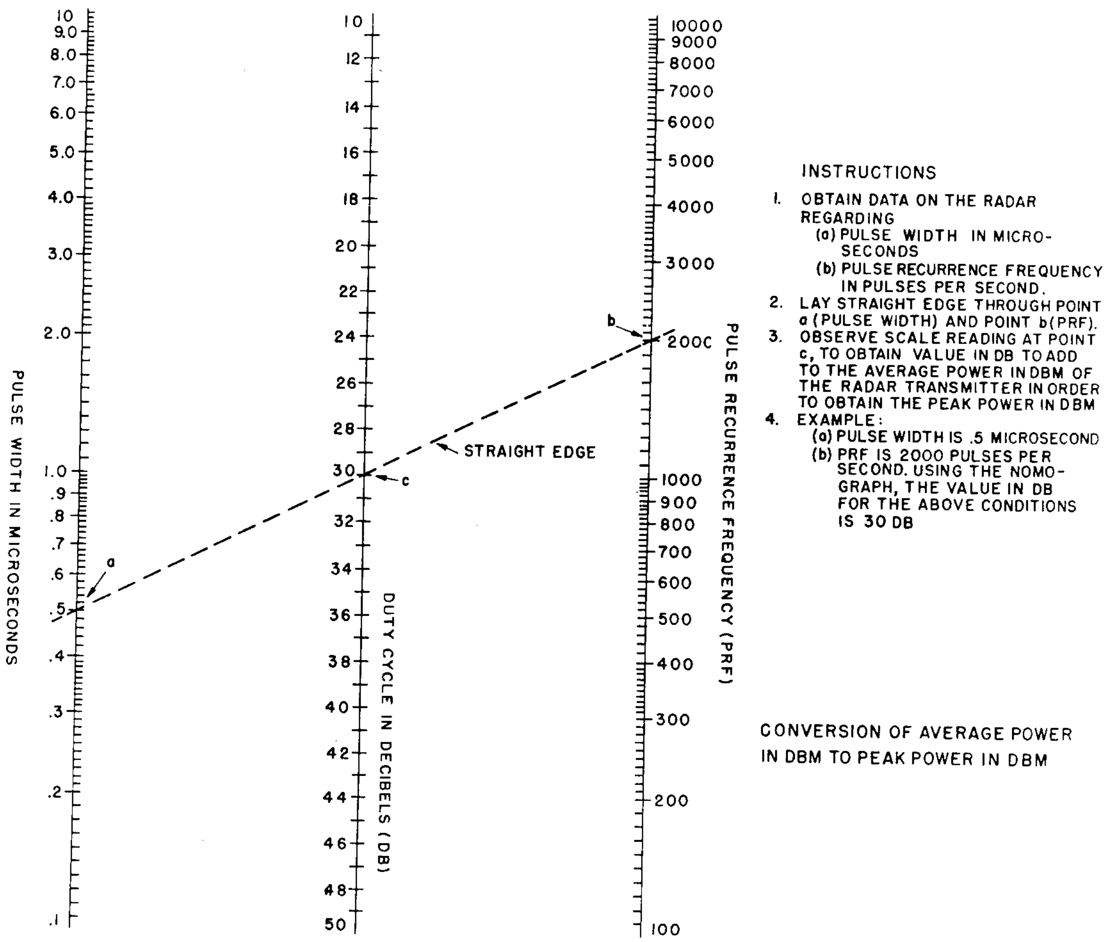


Figure 3-54. Average to Peak (Duty Cycle) Power Conversion Chart

means of the graph in figure 3-52. Some test equipments are calibrated directly in dbm, and no conversion is required. The duty-cycle figure, which depends on the duration of the transmitted pulse and on the pulse repetition rate, can be found directly from the chart shown in figure 3-54.

(3) POWER SAMPLING TECHNIQUES.—The testing of radar power always requires that some method of removing or inserting that power be utilized. There are three principal methods used to accomplish this. They are the test antenna, the r-f probe, and the directional coupler.

(*a*) TEST ANTENNA. — The test or pickup antenna consists of a directional antenna array which is broadly tuned to the radar band to be used. This antenna is placed in the radiation field of the radar antenna, and picks up a certain percentage of the radiated signal. The test antenna may be made portable by mounting it on a tripod frame, or it may be fixed by means of a bracket installed as a part of the radar system. It is common practice to locate the pickup antenna at least one diameter of the radar reflector away from the radar antenna as shown in figure 3-55, and to orient the two antennas for maximum pickup. With this procedure the space attenuation is approximately 30 db. The exact loss either will be given for the particular installation or must be measured. The test procedure for this measurement is discussed in paragraph 3-9.*e*. Any subsequent testing should be done with exactly the same antenna spacing. Another placement method is to clamp the pickup antenna to the edge of the radar reflector in such a manner that the pickup is directed toward the radar antenna feed array. This method is shown in figure 3-56. With the pickup in this position, antenna leakage power is

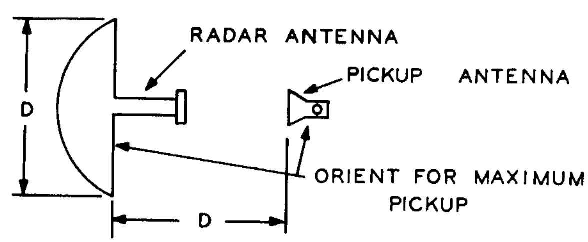


Figure 3-55. Placement of Pickup Antenna

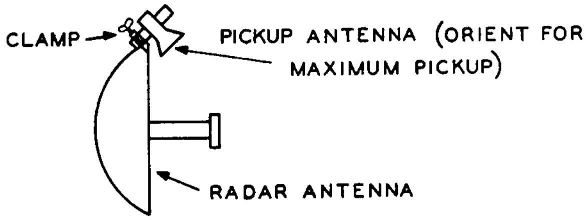


Figure 3-56. Alternate Placement of Pickup Antenna

utilized rather than direct radiation. This procedure had the advantage of allowing operation of the test equipment at various radar antenna positions and the radar antenna does not require careful orientation. The use of a pickup antenna has the important advantage of testing the entire radar system including the radome, if the antenna is placed outside the radome. This enables the testing to show operating efficiency, with all controllable factors included. Four primary disadvantages are associated with the pickup antenna method of sampling power. They are: first, the placement of the antenna is critical; second, antennas are critical to frequency changes; third, it is difficult to make tests during radar scanning; fourth, near-by objects may modify the signal picked up by the antenna.

Near-by objects, or propagation from other sources, may cause reflections and result in large errors in signal pickup. The presence of these reflections may be detected in the following manner: While observing the signal picked up by the antenna, carefully move the pickup antenna closer to the radar antenna. A smooth increase in signal strength should be noted and, if the pickup antenna is moved farther away, a smooth decrease in signal strength should be noted. Any sudden or erratic variations or minimum points indicate that near-by objects are influencing the pickup, and another pickup position must be chosen.

(*b*) R-F PROBE.—The r-f probe consists of a small capacitive probe inserted into the electrostatic field in the r-f transmission line. The greater the penetration of the probe, the greater the power pickup. The penetration of most r-f probes is sufficient to provide 20 db or more attenuation between the main line and the probe output. The probe is fitted with a coaxial connector to facilitate connection to test equipment. In older systems the r-f probe was used extensively, but is now considered obsolete due to the development of the directional coupler. The r-f probe does allow normal radar operation during test, but has the following disadvantages: first, reflections from near-by objects and in the r-f line have a great effect on the attenuation figure; second, probe penetration is very critical; third, the probe is very sensitive to frequency; fourth, the attenuation figure depends upon the load connected to the probe.

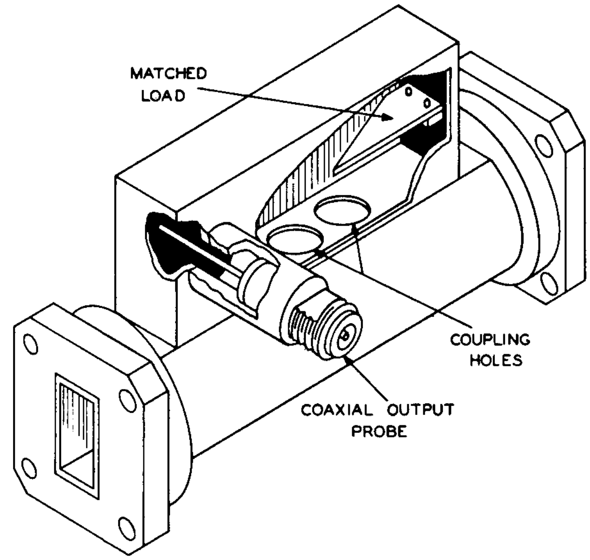


Figure 3-57. Directional Coupler, Cutaway View

(*c*) DIRECTIONAL COUPLER.—The directional coupler, as the name implies, couples, or samples, only energy from a wave traveling in one particular direction in the waveguide. By the proper use of one or more directional couplers, reflected signal power can be prevented from affecting the accuracy of power measurements. Figure 3-57 shows a common type of directional coupler, which consists of a short section of waveguide coupled to the main-line waveguide by means of two small holes, and containing a matched load in one end and a coaxial transition in the other end. The degree of coupling between the main-line waveguide and the auxiliary is determined by the size of the two holes.

The action of this type of waveguide is explained by the diagrams in figures 3-58 and 3-59. In figure 3-58, power is shown flowing from left to right, and two small samples are coupled out at points C and D. Since the two paths, represented by C-D-F and C-E-F, to the coaxial probe are the

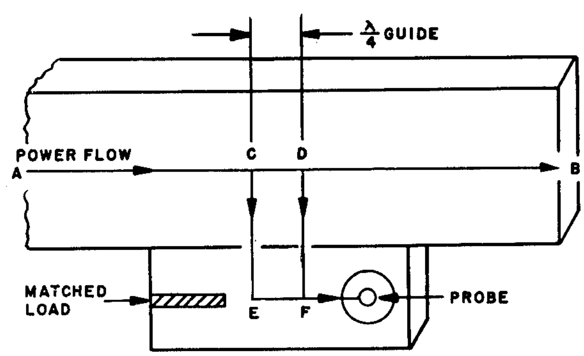


Figure 3-58. Directional Coupler, Showing Direct Power Flow

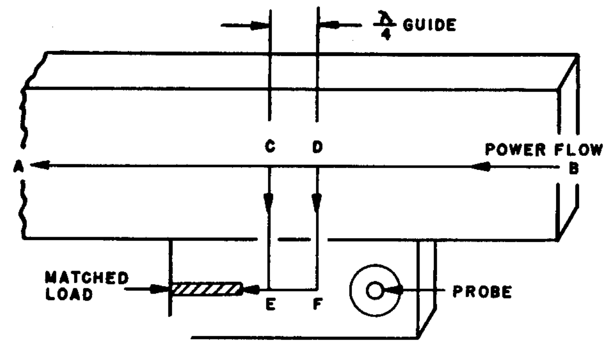


Figure 3-59. *Directional Coupler, Showing Reversed Power Flow*

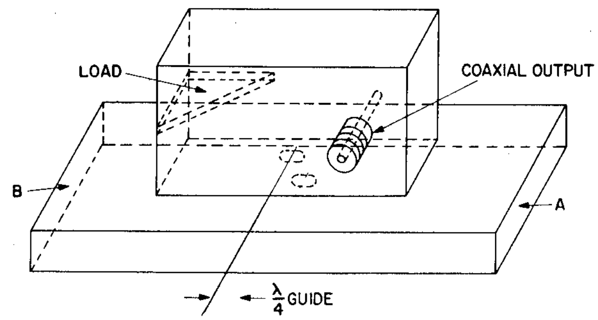


Figure 3-60. *Reverse Directional Coupler*

same length, the two samples arrive at point F in phase and are picked up by the coaxial probe. With regard to the paths to the matched load, however, path C-D-F-E is one-half wavelength longer than path C-E, because the two holes are one-quarter wavelength apart. Therefore, the two samples arrive at point E 180 degrees out of phase, producing cancellation, and the load receives no power. Figure 3-59 shows the same coupler with power flowing in the reverse direction. Again samples are removed at point C and point D. The two paths D-F-E and D-C-E are the same length, and the two samples arrive at point E in phase, and are absorbed by the load. However, path D-C-E-F is a half-wavelength longer than path D-F and the resulting 180-degree phase shift causes cancellation at point E. The result is that the coaxial probe receives power only from a wave traveling from left to right in the main line, and any reflections causing power to flow from right to left have no effect upon the coupled signal. In practice, the attenuation between the coaxial output and the main line for power flowing from left to right is usually adjusted to be over 20 db and is called the nominal attenuation, or simply the attenuation, or the coupling factor. The ability to reject power in the reverse direction is called the directivity attenuation, or simply the directivity, and is usually greater than 20 db. If a certain coupler has a nominal attenuation of 20 db and a directivity of 20 db, the forward attenuation is 20 db and the reverse attenuation is 40 db. If the main line carries a 50-kw pulse the forward output would be 500 watts pulse power and the reverse output would be 5 watts pulse power. Five watts compared with 500 watts is too small to have any great effect.

Forward, or nominal, attenuation does not vary rapidly with frequency, but the directivity does. The rate of variation can be reduced by the use of other designs, however, so that the directional coupler can be operated over a broad band of frequencies. One type of broad-band coupler is the 3-hole coupler. If two directional couplers one-quarter wavelength apart are used, a broader bandwidth is obtained. Since the holes are one-quarter wavelength apart, two couplers would have one hole common to both. This means that the three-hole coupler uses the action of two directional couplers, and the center hole serves as a common coupling to the two end holes. Another type of broad-band directional coupler is shown in figure 3-60. In this unit, the coupling holes are one-quarter wavelength apart and elongated. In addition, the two holes are in opposite halves of the main waveguide, which has the effect of causing a 180-degree phase shift between the coupled signals. This phase shift reverses the direction of coupling, so that when power enters at point A, the two signals arrive in phase at the coaxial output, and when power enters at point B, the two signals arrive in phase at the load and are absorbed. The result is that the coupler in figure 3-60 operates in the reverse manner of that in figure 3-57. In this case the directivity is relatively independent of frequency, but the coupling factor varies rapidly with frequency. A third type of directional coupler, shown in figure 3-61, uses a single hole as the coupling element. This is called the Bethe-hole coupler. Through a single hole, waves are excited in the auxiliary guide due to both the electric field and the magnetic field in the main guide. Because of the phase relations involved in the coupling process, the waves generated by the two types of coupling cancel in the forward direction, but reinforce in the reverse direction. Therefore, in figure 3-61, power entering at point A is coupled to the coaxial output,

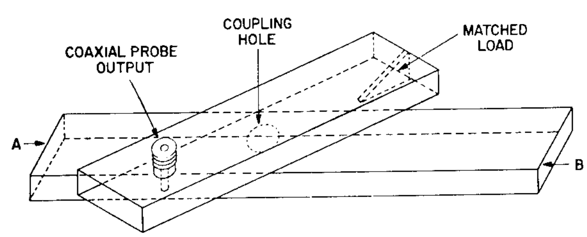


Figure 3-61. *Single-Hole Directional Coupler*

while power entering at point B is absorbed in the dummy load. If the two waveguides were parallel, the magnetic component would be coupled to a greater degree than the electrostatic and the directivity would be poor. By placing the auxiliary waveguide at the proper angle, the amplitude of the magnetically excited wave is made equal to that of the electrostatically excited wave (without changing the latter), and good directivity is obtained. The angle required depends upon the frequency of operation.

Directional couplers serve as stable, accurate, and relatively broad band coupling devices, which can be inserted into a transmission line so as to sample either incident or reflected power. In most cases, however, a directional coupler is made a part of the radar system and is connected so as to sample the transmitted r-f signal. Thus any undesired reflection from near-by objects, though an uncommon occurrence but one which sometimes causes errors, is virtually eliminated as a source of error in power measurements. Directional couplers are also made for use with coaxial transmission lines, and operate in a manner very similar to the two-hole coupler.

(*d*) BIDIRECTIONAL COUPLER. — A bidirectional coupler is used to measure direct and reflected power. As shown in figure 3-62, it consists of a straight section of waveguide, with an enclosed section attached to each side, along its narrow dimension. Each enclosed section contains an r-f pickup probe at one end and an impedance termination at the other end. The impedance termination in this case is in the form of a resistance card. The sections are supplied with energy from within the main waveguide through three openings spaced one-quarter wavelength apart. The r-f probe farthest away from the transmitter is used to measure direct power, and the one nearest the transmitter is used to measure reflected power.

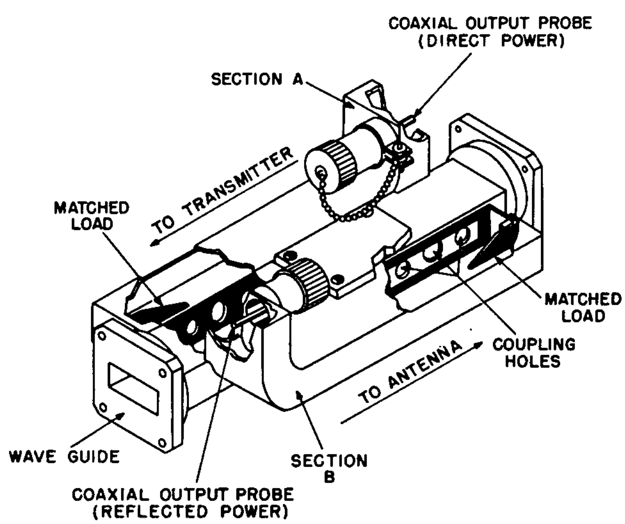


Figure 3-62. Bidirectional Coupler

Energy from the transmitter going toward the antenna enters the enclosed sections through the three openings on each side. Because the openings in each section are spaced one-quarter wavelength apart, the energy travels a quarter wavelength between each of the three openings. The energy coupled into the enclosed sections is attenuated a predetermined amount below that in the waveguide, by the coupling medium. As shown in figure 3-62, the center opening in each of the enclosed sections is larger than each of the holes to either side, thus allowing twice as much energy to enter through that opening.

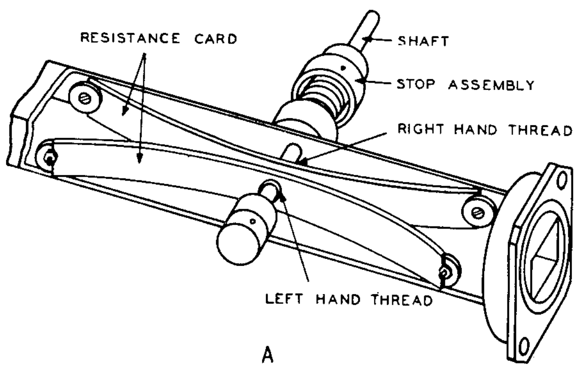
The energy entering the enclosed section farthest away from the transmitter (section A of figure 3-62) will be considered first. Part of the transmitted energy enters this enclosed section, the rest of the energy going to the antenna. This energy, because of the location and dimensions of the openings in section A, enters the enclosed section and combines in phase, and is measured by the direct power probe. A frequency power meter connected to the probe will give a direct indication of the transmitted power in the waveguide. The transmitted energy which entered the other enclosed section (section B of figure 3-62) will be zero, because of the phase displacement of the three openings at that enclosed section. The energy passing the first opening will be 180 degrees out of phase with that of the center opening, and will be in phase with the energy at the third opening. Because the center opening is sufficiently large to supply twice the magnitude of energy as that supplied by either of the two openings, the energy is cancelled. The end of the enclosed section is terminated as described in the first paragraph.

To measure reflected energy due to either standing waves or energy received from targets, section B acts in exactly the same manner as section A when making direct power measurements. Since the direction of energy flow is reversed, the energy will now appear at the reflected power probe in section B. This reflected energy, upon entering section A, will be cancelled out in the same manner as that in which section B cancelled the transmitted power when performing direct power measurements.

(4) ATTENUATORS.—Attenuators in present use are classified as dissipative or non-dissipative. The cut-off waveguide section is a good example of a non-dissipative type attenuator, in that the attenuator merely rejects signals instead of converting them into heat. Dissipative coaxial attenuators are usually short coaxial sections which use resistive material for a center conductor. One such attenuator uses a glass rod, upon which a thin deposit of metal has been sprayed, for a center conductor. Aquadag is sometimes used in place of the metal film.

Short, fixed attenuator sections, called pads, come in a large variety of forms and loss values. For example, the CN-42/UP is a 10-db 50-ohm coaxial attenuator and the CN-43/UP is a 16-db, 50-ohm coaxial attenuator. The coaxial attenuator may be made variable by constructing the resistive section in two telescoping sections, so that the length, and therefore the attenuation, may be varied.

Dissipative waveguide attenuators consist of strips of resistance material placed inside the waveguide, parallel to the electrostatic field. Where the exact value of attenuation need not be known, the strip is made of bakelite or fiber, with an aquadag coating on one side, as shown in part (A) of figure 3-63. Calibrated attenuators are usually of the metalized glass variety, an example of which is shown in part (B) of figure 3-63. As the movable resistance element approaches the center of the waveguide, the power loss is greater. The resistance element may be driven by a dial-and-cam arrangement that is calibrated in db, and the cam surface may be shaped to give any desired spacing of the calibration marks. The ends of the resistive element are tapered to produce as little reflection as possible over a wide band of frequencies.



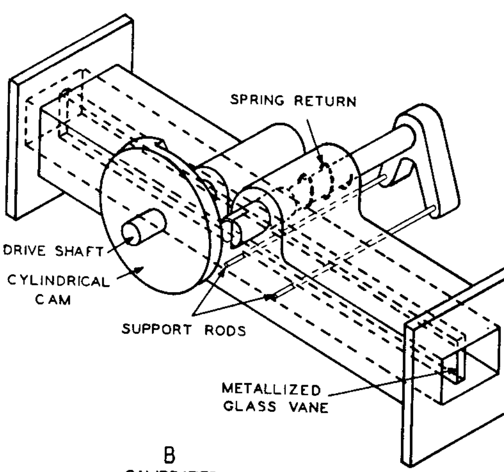


Figure 3-63. Waveguide Attenuators, Showing Construction

Most waveguide attenuators do not have sufficient range to cover all values required in normal use. To overcome this fault, it is common practice to use two attenuators in cascade, and the total attenuation is the sum of the individual readings. In some cases, both attenuators are continuously variable, and in other cases only one attenuator is continuously variable and the other is adjusted in steps. One modern attenuator system has one attenuator with an attenuation range of 7 to 45 db and another one with a fixed attenuation of either 0 or 35 db. Thus the combination provides two ranges of attenuation, 7 to 45 db and 42 to 80 db. The over-all range is said to be 7 to 80 db in two overlapping steps.

Since dissipative attenuators are easily damaged by the application of too much r-f power, the technician must be careful to keep the applied power below the maximum rating of the equipment in use. Power overloads cause the resistive element to blister and peel away from the supporting section, and this condition in turn causes the attenuation value to change, and also produces excessive power reflection. Once an attenuator becomes damaged, it should be discarded. This fault may be detected by inspecting the surface of the attenuator material which should be smooth and of an even coloration. The use of a directional coupler practically eliminates the possibility of power burnout, since a nominal loss of 20 db will normally reduce the radar output to a level below the maximum safe value.

(5) THE THERMISTOR.—The thermistor is a resistance element with a negative temperature coefficient of resistance. When current is passed through a thermistor, heat is generated and the resistance is lowered. The change in resistance may be measured and converted to indicate the heat, in watts, required to produce the change. In microwave measurements, a thermistor is used to terminate a transmission line so that all the power flowing down the line is absorbed in the thermistor, which serves as the load. The amount of r-f power absorbed by the thermistor is indicated by a resistance change. Figure 3-64 shows two types of thermistors in wide use. The disk type is used for temperature compensation and the bead type is used for measurements. In the bead-type thermistor, the active material is in the form of a very small bead, which is supported by two fine wires held in place by heavy pigtail leads imbedded in the glass capsule. The entire capsule is supported by means of the heavy pigtail leads, which also serve as electrical connections. The fine inner wires, which support the bead inside the capsule, are made very small to prevent heat from being carried away from the bead by thermal conduction. To prevent high-frequency skin effect from causing resistance errors, the bead is made small enough that the r-f current

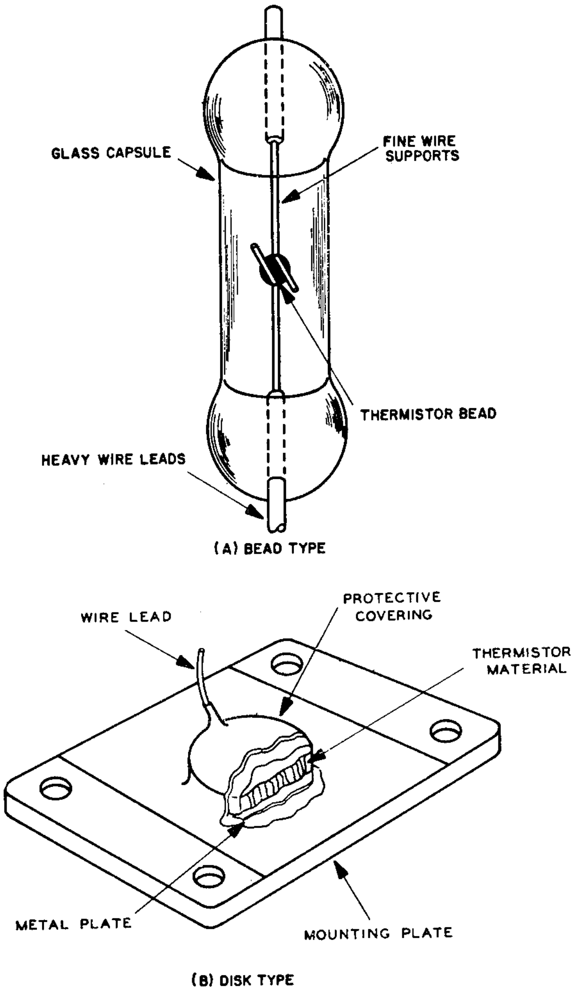


Figure 3-64. Typical Thermistors

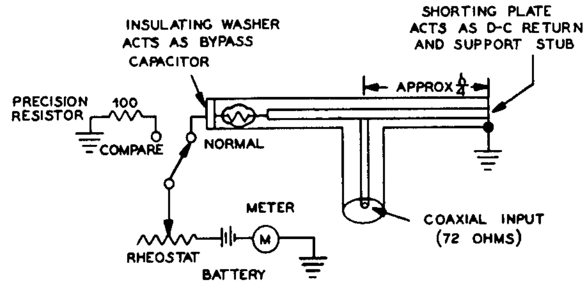


Figure 3-65. Simplified Diagram of Simple Thermistor Power Meter

flow penetrates to the center of the bead. Bead resistance will vary from about 10 ohms hot to about 1000 ohms cold.

b. POWER TESTING—EARLY METHODS.—Two early methods of testing microwave r-f power will be discussed in the text to follow. These methods are known as a simple thermistor power meter, and a crystal application using a synchroscope.

(1) SIMPLE THERMISTOR POWER METER.—An early type of power meter, using a thermistor, is shown in figure 3-65. In this meter, the thermistor is mounted at the end of a coaxial line, and the center conductor of the line is supported by means of a quarter-wave stub, which also serves as a d-c path for the thermistor current. This stub restricts the frequency range of the assembly, and is broadbanded and adjusted at the factory for the desired frequency range. The other end of the thermistor is brought out through an insulating washer that acts as a short circuit to rf but allows dc to flow. The assembly is so constructed that when the thermistor resistance is 100 ohms, an impedance match is achieved. A precision 100-ohm resistor is included to provide a comparison to the thermistor.

(*a*) TEST PROCEDURE.—The following steps describe the technique involved in this test:

1. The rheostat is adjusted until the meter indicates the same current for the thermistor as for the 100-ohm resistor. As a check on the adjustment, the switch is operated to the compare position and the current observed; when the switch is returned to the normal position, the meter reading should not change.

Note

This adjustment allows for different operating temperatures. When the ambient temperature is high, less d-c power is required to drive the resistance down to 100 ohms.

2. The current reading is noted (the reading will vary with ambient temperature), and reference is made to the chart furnished with the meter to determine the current reduction factor for the particular current reading obtained.

3. The rheostat is adjusted to give the reduced current value indicated on the chart. (The reduction in current will cause the thermistor temperature to decrease by an amount that requires 6 mw of r-f power to return the temperature to the previous value.)

4. The r-f power to be measured is supplied to the coaxial input. When 6 milliwatts of r-f power is present, the meter will again indicate the current value noted in step *2*.

Thus, the instrument serves to indicate a standard reference power level. One example of this type meter is the 60-ABU power meter, which is calibrated to indicate either 6 or 10 milliwatts.

(2) CRYSTAL APPLICATION USING SYNCHROSCOPE.—In this method a means of measuring power is described.

(*a*) TEST SETUP.—Figure 3-66 shows the setup and test equipment required to utilize the above method. The test equipment consists of

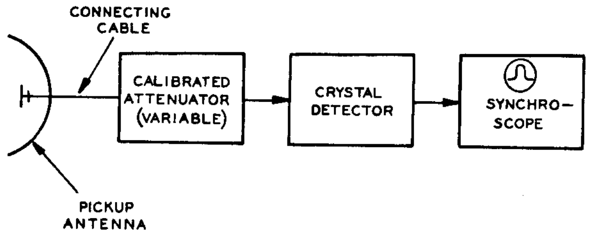


Figure 3-66. Test Setup for Crystal Application Using Synchroscope

a pickup antenna for obtaining a sample of the transmitted r-f power, a calibrated variable attenuator, a crystal detector, and a synchroscope.

1. PICKUP ANTENNA.—The pickup antenna is provided to sample a known amount of the transmitted power. In one early equipment, the antenna consisted of a dipole and parabolic reflector enclosed in a Plexiglas housing. In use, the antenna is placed at a certain distance from the radar antenna, the two antennas are oriented to point directly at each other, and the polarization of the pickup antenna is adjusted to agree with that of the radar antenna. The pickup antenna, which is located about 10 feet above ground, has directional properties to minimize the effect of reflection from ground and near-by objects.

2. ATTENUATOR.—An attenuator is a device that causes a reduction of signal power. The degree of reduction, or attenuation, may be stated as a ratio; for example, if 10 watts is fed into an attenuator, and only 1 watt appears in the output, the attenuation of power is 10 to 1. Two such units in cascade would produce an attenuation ratio of 100 to 1. In older microwave equipments, the most commonly used attenuator is the cut-off waveguide type. In this type, a circular pipe, too small to act as a waveguide, is made so as to have an adjustable length as shown in figure 3-67. The longer the cut-off section, the greater the attenuation. In use, the sliding section is operated by means of a rack-and-pinion gear assembly, and a calibrated dial which drives the pinion gear gives the attenuation at each setting. The resistive disks in the attenuator serve to provide an impedance match over a wide range of frequencies.

3. CRYSTAL DETECTOR.—The crystal detector is a conventional radar crystal, such as the 1N21B, which is used at wavelengths around 10 cm. The crystal circuit matches the input-line impedance and feeds a 72-ohm load.

4. SYNCHROSCOPE.—The synchroscope, which is widely used in radar testing, will be described in detail at this time, since an understanding of its operation is important to this discussion.

The synchroscope is an adaptation of the oscilloscope. A trace is produced only when it is initiated by an input trigger, as contrasted with the continuous sawtooth sweep provided by the oscilloscope. Synchroscope circuits are similar to oscilloscope circuits except for the signal channel and the sweep channel. These circuits are shown in block diagram form in figure 3-68. Refer to paragraph 2-8.*a.*(5) for a general discussion of these circuits.

The signal channel includes an input circuit, which is usually in the form of a 72-ohm adjustable-step attenuator. Various degrees of attenuation are available, and the dial is calibrated to indicate how much attenuation is present. This attenuator ensures that all signals, regardless of amplitude, produce about the same input level to the amplifier section. Following the attenuator is an artificial delay line, which is a low-pass filter with a cut-off frequency higher than the highest frequency to be passed, and which has an impedance of 72 ohms. The delay line is terminated with a 72-ohm gain control. One purpose of this delay line is to delay the signal to be observed until the sweep trace has been initiated by a portion of the input signal which is not delayed. If the delay line were not used, the initial portion of the waveform would not appear on the trace because a certain amount of time is required for the input signal voltage to rise to the level needed to trigger the sweep circuit. With the delay line in use, the signal does not reach the amplifier until ½ microsecond after the trace starts; as a result, the entire pulse is seen. A secondary purpose of the delay line is to

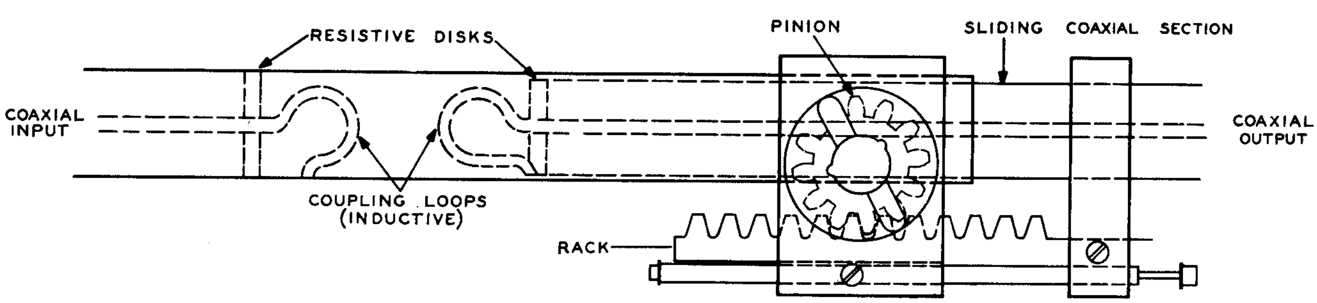


Figure 3-67. Cut-Off-Waveguide-Type Attenuator

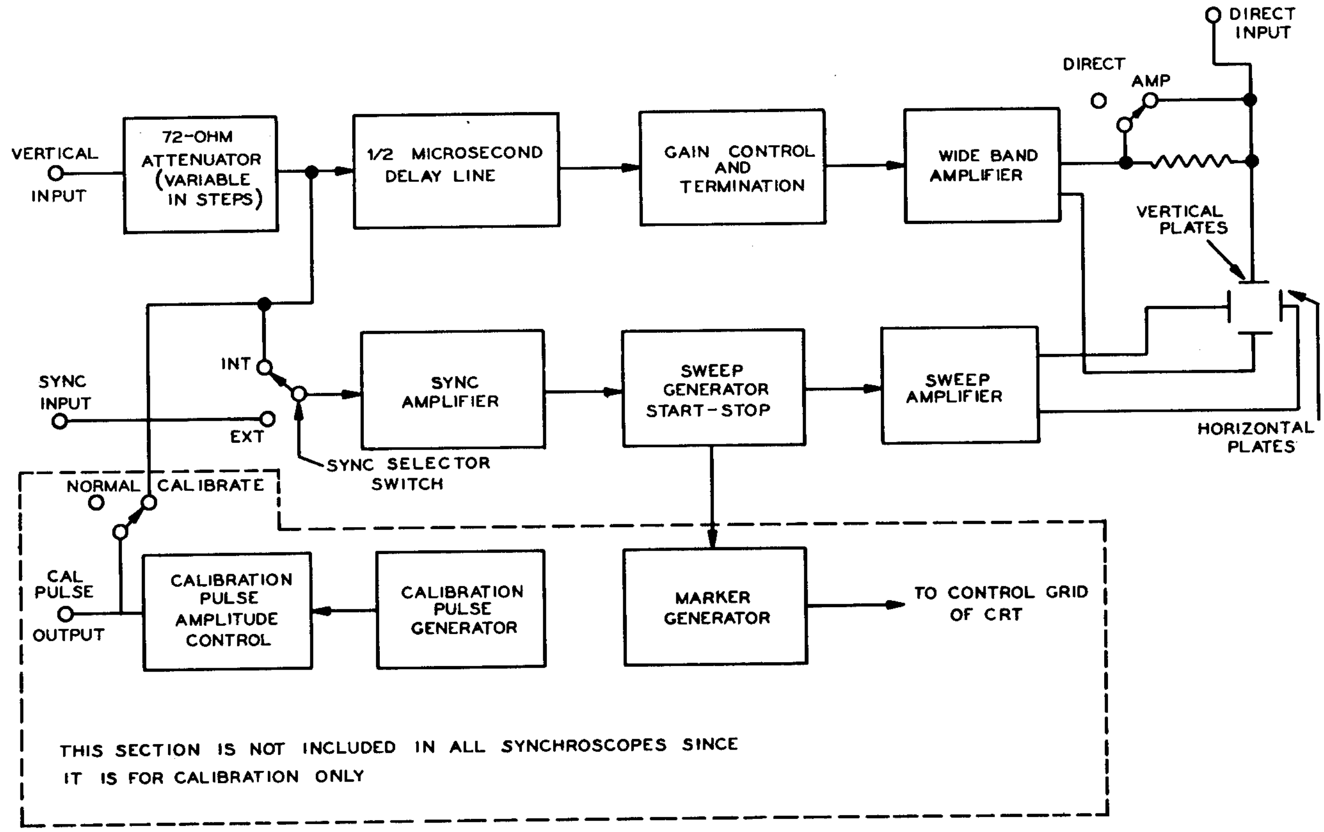


Figure 3-68. ***Block Diagram of a Typical Synchroscope***

provide, by means of reflection, a series of accurately spaced pulses suitable for calibration of short time intervals. To accomplish this purpose, a switch is provided to cause a mismatch in the termination of the delay line, so that when a sharp pulse is fed into the line, a series of reflections will occur similar to those shown in figure 3-69. Since the time required for a pulse to travel down the line and back is 1 microsecond, a series of pulses, occurring 1 microsecond apart is produced. Of course, each successive pulse is smaller because of losses in the delay line, but a sufficient number are visible for most high-speed calibration purposes.

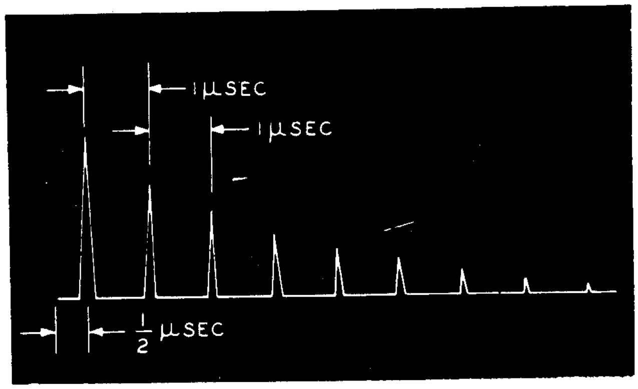


Figure 3-69. ***Pulse Reflection on a Mismatched Line***

The gain control feeds a wide band or video amplifier, which is connected to the vertical deflection plates. In addition, an external connection is provided to the vertical plates.

The horizontal circuit consists of a sync switch for either internal or external sync, a sync amplifier with a gain control, and a start-stop sweep generator, which will not develop a sweep voltage until a pulse of sufficient amplitude is fed in. The duration of the sweep, or sweep speed, is made adjustable for a very few microseconds to about 250 microseconds. The sweep generator is followed by a conventional horizontal amplifier. Since the trace is triggered by the input signal, the synchroscope may be used to observe non-periodic pulses, such as those occurring in a radar system that has an unstable PRF.

In later designs, it is common to find provisions for calibration of input voltages and sweep time. Voltage calibration is made by comparing the unknown voltage with a variable-voltage pulse of known value, generated internally. The calibrating pulse is adjusted to be equal in amplitude to the unknown voltage, and the value is read from the dial that controls the calibrating pulse. Sweep-time calibration is made with the aid of marker pulses produced by accurately adjusted tuned circuits. The marker pulses appear on the trace as a series of bright dots spaced at intervals chosen by the

operator. In a typical synchroscope, marker intervals of .2, 1, 10, 100, and 500 microseconds may be selected in accordance with the time duration of the pulse under test; for greater accuracy interpolation may be used.

When the synchroscope is used with the setup shown in figure 3-66, a pulse similar to the one shown in part (A) of figure 3-70 may be observed on the scope. This pulse represents the r-f output of the radar transmitter. The pulses shown in parts (B), (C), and (D) of the same figure represent improper magnetron operation, and could result from mode jump, mode skip, or mode shift.

(*b*) TEST EQUIPMENT CALIBRATION PROCEDURE.—In practice, the crystal detector and synchroscope must be calibrated. The usual method is to feed a 6-milliwatt pulse of rf to the crystal, and adjust the gain of the scope to give a one-half inch pulse. The controls must not be varied after calibration. One calibration procedure is as follows:

1. Tune a signal generator, such as a TS-418/U, to the approximate transmitter frequency.

2. Feed generator output to a standard power meter, such as the TS-107/TPM-1.

3. Adjust signal generator for c-w output, and set output level for 6 milliwatts as indicated on power meter.

4. Remove power meter, and feed generator output to crystal detector and synchroscope. Set generator for pulsed output. (The peak pulsed-generator power must be the same as the average c-w power.)

5. Adjust synchroscope gain control to give one-half inch deflection on synchroscope.

(*c*) ADDITIONAL CALIBRATION PROCEDURE.—To simplify the calibration procedure, some early test units incorporated a meter and rheostat in series with the crystal detector. The resistance of the meter circuit is high enough to prevent loading, and the rheostat is set so that the meter indicates a given current when 6 milliwatts of c-w power is fed to the crystal. This meter must be checked against the standard power meter at frequent intervals to ensure calibration. When this system is used, the synchroscope calibration procedure is as follows:

1. Tune signal generator to approximate transmitter frequency.

2. Feed generator output to crystal detector.

3. Set generator for c-w output, and adjust output for standard meter reading.

4. Adjust generator for pulsed output, and set synchroscope gain for one-half inch deflection.

Note

The calibration meter will read only during c-w calibration. When pulsed output is used, the average meter current is too low to produce a readable deflection.

(*d*) POWER MEASUREMENT PROCEDURE.—The synchroscope and crystal are now calibrated for a 6-milliwatt level and are ready to test transmitter power. Transmitter power is measured as follows:

1. Place pickup antenna some accurately known distance from radar antenna, and orient the two antennas for maximum pickup.

2. Connect pickup antenna to calibrated attenuator by means of special cable supplied with antenna, and connect attenuator output to crystal detector and synchroscope.

3. Adjust attenuator for one-half inch pulse as indicated on scope.

4. Find total attenuation between crystal detector and radar antenna.

5. Peak power (in watts) is .006 multiplied by the attenuation ratio.

(*e*) SOURCES OF ATTENUATION.—In the method of testing r-f power discussed above, the total attenuation arises from four sources. These sources are: first, loss between radar antenna and output of pickup antenna, called space loss; second, antenna cable loss; third, attenuator zero loss—when the attenuator is set to zero, there is still a certain amount of loss inherent in the attenuator and cables; and fourth, attenuator loss.

The data on space loss is supplied in test equipment operating instructions for certain antenna placements on given radars and can be reproduced. This loss depends to a certain extent upon frequency, and correction must be made to give the loss at any specific frequency. Antenna cable loss and attenuator zero loss are measured at the factory and marked on the equipment, but the actual loss will vary with age and atmospheric conditions

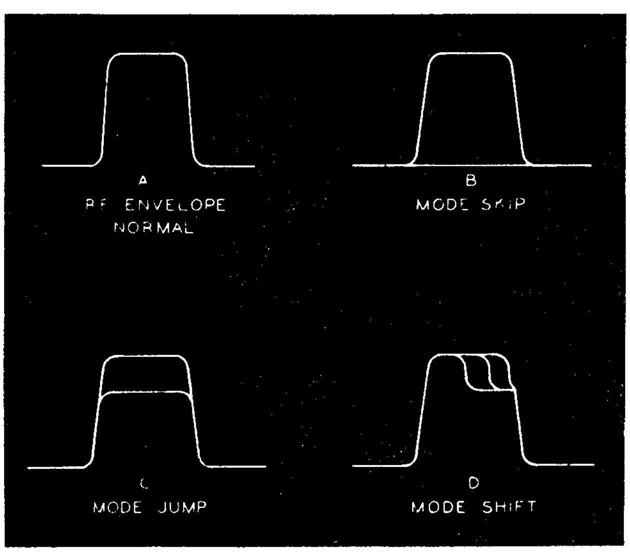


Figure 3-70. Magnetron Output-Pulse Characteristics

and should be tested periodically, as well as after periods of disuse.

(*f*) TEST LIMITATIONS.—Measurement of power by the method discussed above offers the following advantages: First, peak power is measured directly. Second, the width of the r-f pulse can be observed. Third, the shape of the r-f pulse can be observed.

This method has the following disadvantages: First, the involved calibration procedure reduces accuracy. Second, the whole procedure is somewhat complicated. Third, frequency changes necessitate recalibration of losses.

c. POWER TESTING — LATEST TECHNIQUES.—Modern methods of measuring power make use of a setup shown in figure 3-74, which incorporates an attenuator and thermistor bridge. The coupling device is usually a directional coupler, but a pickup antenna may be used if desired.

(1) THERMISTOR BRIDGE METHOD.—The thermistor bridge and attenuator method of power measurement provides an indirect indication and relies upon factory calibration of the equipment for accuracy. However, the simplicity of operation makes the method very desirable for radar maintenance work.

The complicated procedures found necessary in the early thermistor power meters were due to the effect of ambient temperature changes causing changes in thermistor resistance. This difficulty has been corrected by the development of the compensated thermistor bridge circuit, shown in figure 3-71. This circuit incorporates a Wheatstone bridge circuit, which is made up of three resistors and a bead-type thermistor. The bead thermistor acts as a matched load for the r-f line when the bridge is balanced. Two disk-type thermistors are used for temperature compensation, and are in thermal contact with the section of the r-f line containing the bead thermistor. Figure 3-72 shows the construction of two typical thermistor mounts, the coaxial and the waveguide types.

The resistance of the bead thermistor may be

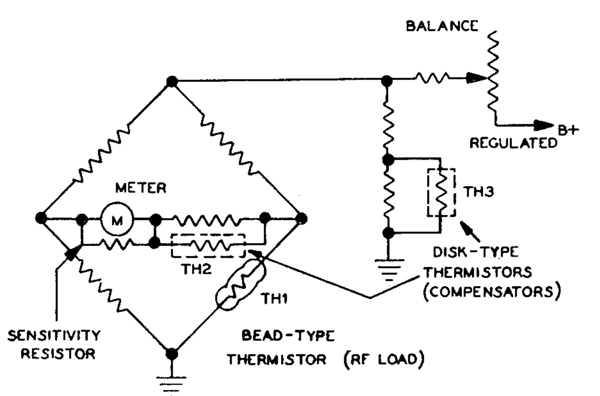


Figure 3-71. Compensated Thermistor Bridge Circuit

varied by means of the balance rheostat. The bridge is balanced by electrically adjusting the circuit to a point where one milliwatt of r-f power will produce zero meter current. A zero-centered type meter is used, and the value of the sensitivity resistor is factory adjusted so that with full scale meter reading one milliwatt of r-f power is required to restore the reading to midscale.

(*a*) BRIDGE TEMPERATURE COMPENSATION.—Temperature compensation of the bridge is necessary for two reasons: first, bridge balance must be maintained, and, second, sensitivity must remain constant under varying temperature conditions. In figure 3-71, thermistor TH3, with its associated resistors, compensate for any unbalance due to temperature variation, as follows: As the ambient temperature rises, the resistance of the bead thermistor drops, so that if no compensation were provided, an unbalanced condition would occur. At the same time, however, the resistance of thermistor, TH3, decreases, causing a reduction in the d-c voltage applied to the bridge. The resulting reduction in d-c bridge power allows the resistance of the bead thermistor to return to normal, with the result that the bridge balance is maintained. Since rf is applied only to the bead thermistor, compensation does not depend upon r-f power.

At high ambient temperatures, the value of dc applied to the bridge is low. This condition results in reduced bridge sensitivity and, if uncompensated, would result in errors in measurements. Compensation is provided by thermistor, TH2, which is effectively in series with the indicating meter. At high temperatures, where bridge sensitivity is reduced, this thermistor presents a lower series resistance to the meter and, therefore, increases the meter sensitivity in the same proportion as the loss of bridge sensitivity. Thus, the over-all sensitivity is maintained essentially constant at different temperatures. In practice most bridge circuits are designed to give exact readings at temperaures of 0, 30, and 60 degrees centigrade. At other temperatures, a slight error exists but is too small to be considered in radar maintenance.

(*b*) BRIDGE OPERATION.—Utilization of the thermistor bridge greatly simplifies the measurement of r-f power. With the equipment turned off, the meter is mechanically zero adjusted to center scale. A standard power meter scale is shown in part (A) of figure 3-73. Then the equipment is turned on, and the balance control is operated to produce deflection to the balance point on the meter. The meter is now ready to indicate power. A midscale reading indicates 1 mw, and a full-scale reading indicates 2 mw. The calibration is nearly linear, but at any point except midscale, the bead thermistor presents an r-f mismatch, causing errors in the indications.

In some equipments the meter scale is marked

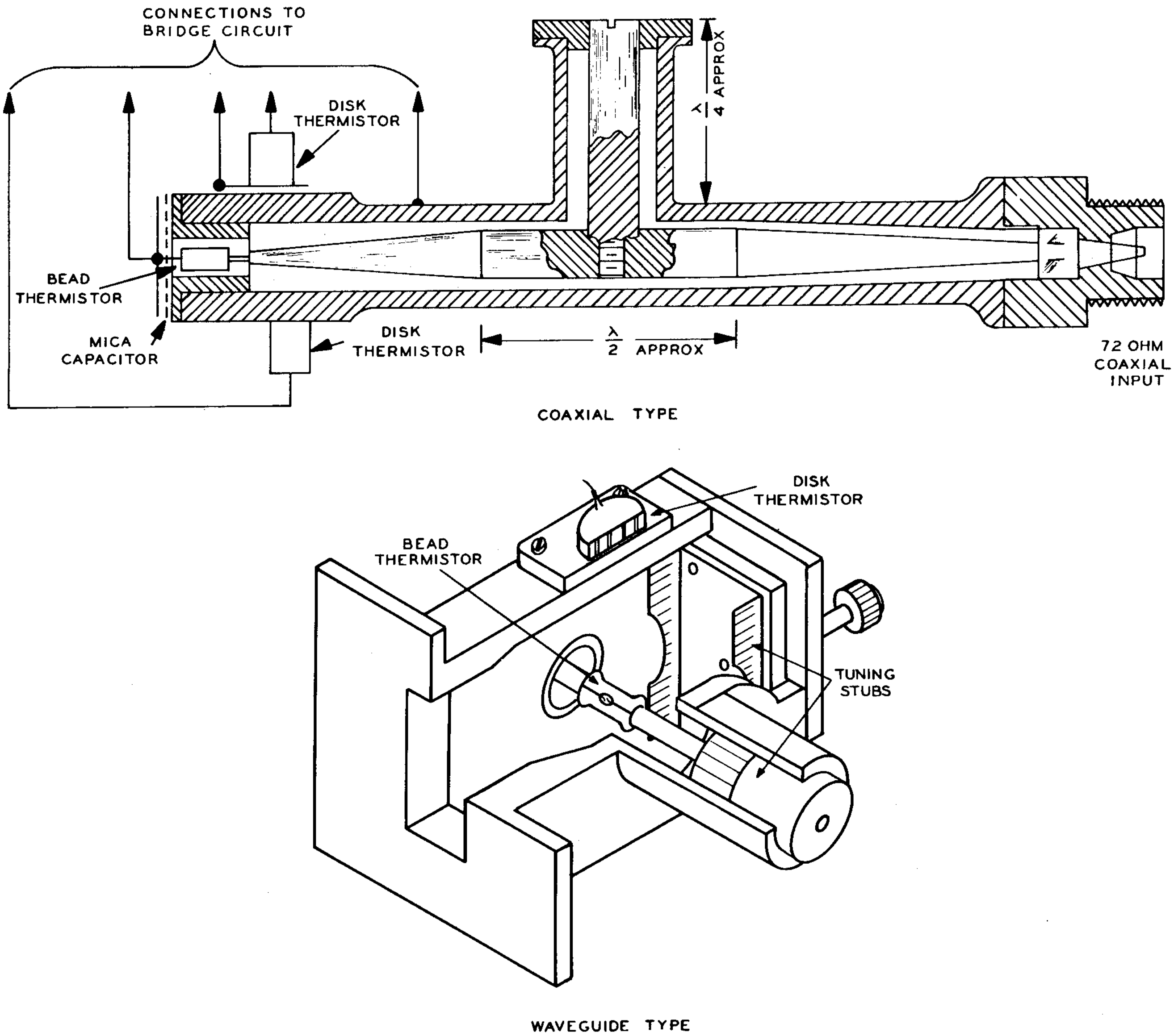


Figure 3-72. Typical Thermistor Mounts, Showing Construction

directly in power or dbm; for example, part (B) of figure 3-73 shows meter calibration in milliwatts and dbm.

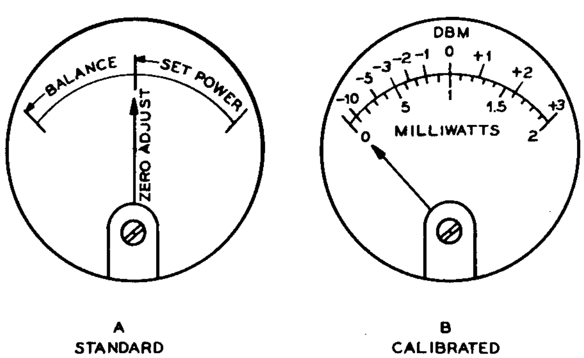


Figure 3-73. Typical Power-Meter Scales

Thermistor bridges measure only the average power level, due to an effect called thermal time lag. The resistance of a thermistor changes only as rapidly as the bead heats or cools. Since this heat transfer is a relatively slow process, the time required for an appreciable change in resistance is great compared to the pulse period of the average radar. In practice, the time-lag period includes many radar pulses, with the result that a true average-power indication is obtained. One obvious disadvantage of the thermistor bridge lies in the fact that erratic or sudden variations in power level often occur too rapidly to be detected with this type of power test equipment.

(*c*) TEST PROCEDURE.—The test setup for this method is shown in figure 3-74. The signal from the coupling device is attenuated until the

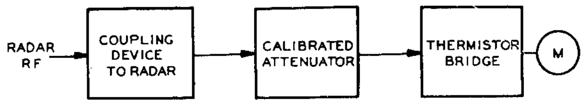


Figure 3-74. ***Test Setup for Thermistor Bridge Method of Power Measurement***

thermistor bridge shows one milliwatt of power. The input power is then calculated by finding the total attenuation between the radar and bridge circuit, using the formula:

Power (dbm) = coupling loss (db) + cable losses (db) + attenuator reading (db)

If peak power indications are desired, the duty cycle, in db, must be added to the other losses. For example, if a given radar has a pulse width of .5 microseconds and a PRF of 2000, corresponding to a duty cycle of .001 (30 db), and if the average power is 100 watts (50 dbm), the peak power is 50 dbm plus 30 db, or 80 dbm, which corresponds to 100 kw.

d. POWER TEST EQUIPMENT CALIBRATION.—In order to provide an accurate periodic check on power testing equipment, it is desirable to set up a calibration standard. Each individual test instrument may be checked against the standard at periodic intervals (such as quarterly), and any calibration errors may be noted and taken into account during testing. If a certain test set suddenly shows a large calibration error, it should be overhauled before being returned to service.

One calibration standard is known as the water-load power meter, which is illustrated in figure 3-75. A brief description of power measurement using the water-load method will be found in paragraph 3-5.*d.*(1). The water load provides a non-reflecting termination for the r-f line, and the r-f output, which is completely absorbed by the water, produces a rise in the water temperature. The water is circulated through the load by means of a pump, and the temperature of the water going into the load is compared with the temperature of the water at the outlet. If the rate of water flow and the difference in temperature at the input and output are known, the absolute power in watts is easily calculated.

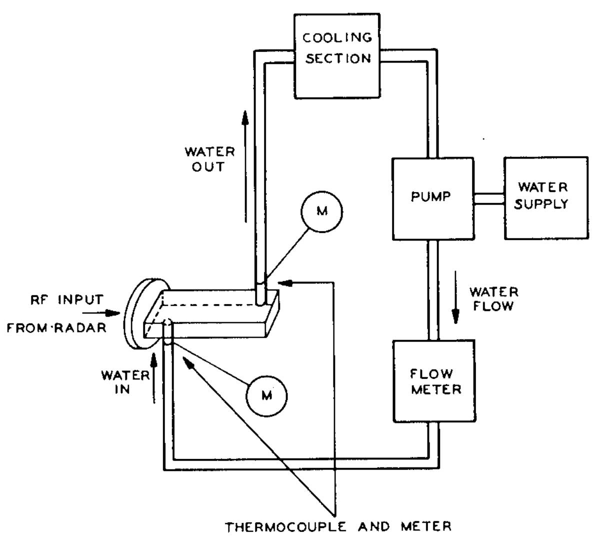


Figure 3-75. ***Water-Load Power-Test Setup Used for Calibration***

(1) TEST PROCEDURE.—The procedure for checking a thermistor bridge and attenuator is as follows:

(*a*) Connect water-load test equipment to the r-f output of a radar set, as shown by the setup in figure 3-75.

(*b*) Connect thermistor bridge and attenuator to the same r-f line by means of a directional coupler.

(*c*) Start water flow with radar set off, and establish uniform rate of flow. (Care must be taken to eliminate air bubbles.) The two thermocouple meters should read the same temperature.

(*d*) Turn the radar transmitter on. A rise in output water temperature should be noted. Allow operation to continue until there is no further change in the temperature difference between water input and output. This is called the equilibrium condition.

(*e*) Note the temperature difference and the rate of water flow.

(*f*) Measure the r-f power with the thermistor bridge and attenuator test set.

(*g*) Convert readings taken in step (*e*) to power in watts, using the following formula:

$$\text{Power (in watts)} = 4.18\ m\ C_p\ \Delta T$$

Where m = water flow in grams per second
C_p = specific heat of water in calories per gram per degree centigrade
ΔT = temperature difference in degrees centigrade.

(*h*) Compare result obtained in step (*g*) with the power reading obtained in step (*f*). The difference between the two values is the error in the thermistor bridge and attenuator test set.

e. ATTENUATOR CALIBRATION.—The directional coupler is the only coupling unit for which the coupling loss is accurately predetermined. Each coupler is accompanied by a tag or stamped nameplate which gives the coupling loss and, in some cases, the midband directivity. Several variable factors are inherent in the pickup antenna method of coupling. The attenuation loss (or space attenuation) between two antennas is given by the formula:

$$\text{Attenuation (db)} = 10 \log \frac{158d^2}{g_1 \; g_2}$$

Where d = spacing between antennas in centimeters

g_1 = gain of radar antenna in terms of power ratio

g_2 = gain of pickup antenna in terms of power ratio

The formula is accurate only when the antennas are spaced more than one reflector diameter apart. It may be seen from this formula that, for any given pickup antenna, the attenuation is determined by the gain of the radar antenna and the spacing between antennas. Furthermore, the gain of the pickup antenna is dependent upon the operating frequency. For convenience in future measurements, it is desirable to establish a standard spacing for the pickup antenna and measure the attenuation at several points in the operating-frequency band.

Connecting cables present another source of test error, because their attenuation value increases with age, and may vary depending upon atmospheric conditions and handling. Flexing of the cable may cause considerable variation in attenuation, and should be avoided, if possible. Most cables are factory calibrated, and are marked to indicate the attenuation in db. Since cable loss is subject to such wide variation, all connecting cables should be checked periodically at the operating frequency, under normal atmospheric conditions.

(1) POWER TESTING TECHNIQUES.—The performance-testing of radar systems is based upon a method that consists of establishing a standard reference power level and, by means of attenuation, comparing all signals to the reference level. For example, a transmitter power test is made by measuring the attenuation necessary to reduce the power to 1 milliwatt, and receiver sensitivity is checked by measuring the attenuation necessary to reduce 1 mw to the minimum-discernible-signal (MDS) level.

Temperature-compensated thermistor bridges have made it possible to provide a very accurate check of the reference power level, and broadbanding techniques have made the reference measurements accurate over an entire radar band. For example, a modern thermistor mount may be accurate over the frequency range of 8500 to 9600 mc. Broadband attenuators have been developed to a point where reliable attenuation indications make accurate power measurements possible. The metallic-film-on-glass type attenuator provides an accurate and stable source of attenuation.

(2) CALIBRATION STANDARDS.—If reliable attenuation figures are to be attained, some type of calibration standard must be employed. The calibration standard generally used is the cut-off type calibrated attenuator, which has the advantage of possessing linear dial markings; that is, the degree of dial rotation required to change the attenuation from 20 to 23 db is the same as for a change from 50 to 53 db. This linear characteristic makes the attenuator very useful for calibration purposes in cases where the exact attenuation is not important but rather the change in attenuation must be known.

Under the conditions where resistive coaxial or waveguide attenuators are used, it is necessary to rely upon calibration figures supplied in the maintenance literature accompanying the attenuators. Correct results will be obtained as long as the unit is not subjected to mishandling or overload. Once a calibrated resistive attenuator is damaged, either mechanically or electrically, it should be discarded, because the calibration is no longer reliable, and the VSWR may be excessive. In the waveguide type of attenuator which employs a metalized glass vane as the resistive element, the glass vane is easily cracked or broken by mechanical shock.

(3) CALIBRATION ACCURACY.—The calibration procedures about to be described are usually performed when a particular device is suspected of being in error or is not marked. The accuracy of such measurements is dependent upon the accuracy of the calibrated attenuators and directional couplers used. Errors may result from operational errors due primarily to carelessness. The following precautions should always be observed. In general, these precautions apply to systems testing as well as to calibration procedures.

(*a*) Allow all associated equipment to reach operating temperature. A 1-hour warm-up is preferable; however, ½ hour can be considered as a minimum time.

(*b*) Subsequent testing should be done under as nearly identical conditions as possible, so as to minimize corrections otherwise made necessary by variations in temperature, pressure, relative humidity, and other operating conditions.

(*c*) If conditions do change, apply corrections as specified in instructions or maintenance literature.

(*d*) Make sure that all cable connections and fittings are tight.

(*e*) Repeat those measurements considered critical several times and strike an average of the readings obtained.

(4) PICKUP-ANTENNA CALIBRATION.—The attenuation between the radar and pickup antennas may be calibrated by any one of several methods. Three methods are given in the text to follow. The first and third methods rely upon the accuracy of a calibrated directional coupler, while the second, or alternate test procedure, does not.

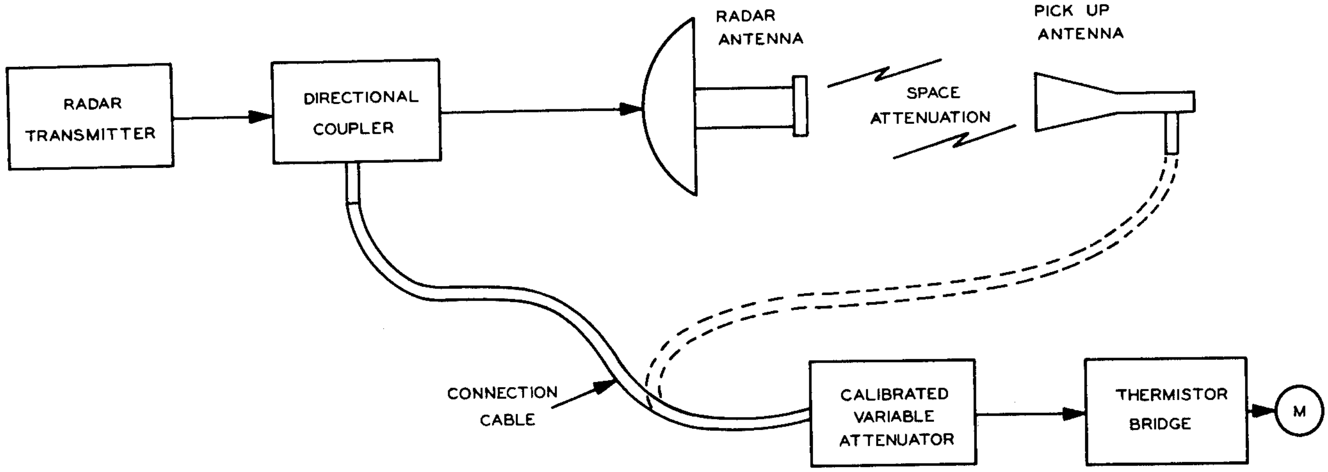


Figure 3-76. Test Setup for Pickup-Antenna Calibration—First Method

(*a*) TEST PROCEDURE.—The first method can be utilized by performing the steps listed below:

1. Refer to figure 3-76 for the block diagram of the test setup.

2. Install pickup antenna in a position at least one radar-dish diameter away from the radar antenna or farther. Make sure that this position can be duplicated in any subsequent tests.

3. Orient both antennas for maximum pickup.

4. If radar equipment has no built-in directional coupler, install one temporarily. The calibration of this coupler must be reliable.

5. Use the thermistor bridge and attenuator type of power meter to monitor the power.

6. With power meter connected to directional coupler, set calibrated attenuator for a 1-mw power reading. Record attenuator reading.

7. Transfer the connecting cable to pickup antenna, reset attenuator for 1 mw, and record new attenuator reading.

8. The space attenuation between the antennas is a combination of the directional-coupler attenuation and the difference in dial readings in steps *6* and *7*.

Note

1. If dial readings in steps *6* and *7* are the same, the space attenuation is equal to the directional-coupler attenuation.
2. If reading in step *6* is greater than that in step *7*, space attenuation = coupler attenuation + (step *6* reading — step *7* reading).
3. If reading in step *6* is less than that in step *7*, space attenuation = coupler attenuation — (step *7* reading — step *6* reading).

(*b*) ALTERNATE TEST PROCEDURE. —The second or alternate method permits testing at different frequencies, and therefore is more flexible. The procedure is described in the steps given below:

1. Refer to figure 3-77 for block diagram of test setup.

2. Operate radar with the transmitter off to prevent damage to adapter, cables, or calibrated attenuator, and employ manual tuning of the receiver.

3. Use the same test setup as was utilized for the measurement of MDS described in RADAR TESTING—RECEIVER PERFORMANCE. The signal generator may be either the FM or pulsed type.

4. Synchronize A-scope sweep with pulsing of signal generator. (The method of synchronization will depend upon the radar used.) A synchroscope may be used for the A scope, in which case, the signal generator is synchronized by the same pulse used to trigger the synchroscope.

5. Install pickup antenna as described in step *2* of the first method given under PICKUP-ANTENNA CALIBRATION.

6. Orient the two antennas so that maximum pickup is obtained.

7. Tune signal generator to desired frequency, establish a 1-mw c-w level, and operate generator for a pulsed output, or an FM output, if an FM generator is used.

8. Set receiver gain for about ⅛ inch of noise on A scope.

9. Tune radar receiver to signal-generator frequency, as indicated by maximum amplitude of received pulse. Check frequency with frequency meter.

10. Adjust attenuator to give about a ½ inch pulse. Be careful to check for saturation by reducing the attenuation 1 db. If the receiver is not saturating, a rise of about 12 percent can be expected.

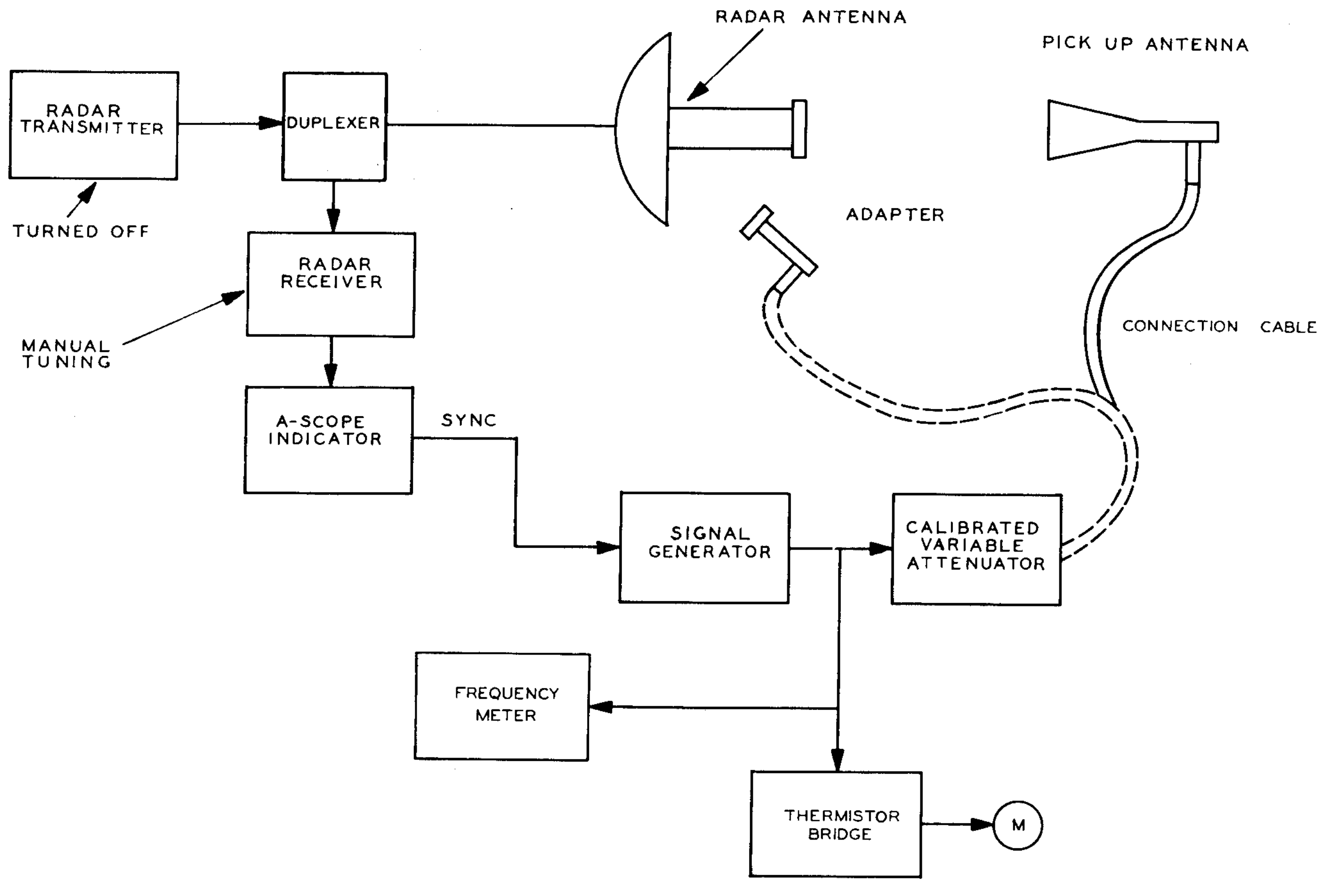


Figure 3-77. Test Setup for Pickup-Antenna Calibration—Second Method

11. Determine exact pulse height in either scale divisions or inches. Do not touch the receiver controls after this point.

12. Remove radar-antenna feed assembly, and substitute the adapter. Connect adapter to the connecting cable.

13. Increase attenuator setting until pulse amplitude obtained in step *11* is reached.

14. The change in attenuator setting is the space attenuation between the two antennas.

15. Repeat the measurement at several points in the operating-frequency band, and plot a graph of space attenuation versus frequency.

(*c*) ADDITIONAL TEST PROCEDURE.—The following method is used when it is impractical to remove the radar antenna feed assembly. This method has other advantages in that the test is made with the radar transmitter turned on and that no external sync is required to trigger the signal generator. The procedure is given in the steps below:

1. Refer to figure 3-78 for block diagram of the test setup.

2. Install pickup antenna as described in the first method.

3. Orient both antennas for maximum pickup.

4. If the radar has no built-in directional coupler, install one temporarily. It is necessary that the calibration of this coupler be reliable.

5. Use the test setup for MDS measurement as described in RADAR TESTING—RECEIVER PERFORMANCE. Either the FM or pulsed signal generator may be used.

6. With test equipment connected to directional coupler, set receiver gain to provide 1/8 inch noise level on A scope.

7. Tune signal generator to desired frequency, and establish a 1-mw c-w output.

8. Operate signal generator for pulsed or FM output, as the case may be, and tune receiver to frequency of signal generator. Check frequency by observing absorption response of frequency meter on A scope.

9. Adjust attenuator to provide about 1/2 inch pulse, and check for saturation. Note attenuator reading.

10. Transfer the connecting cable to pickup antenna, and adjust attenuator to give some pulse amplitude as in step *9*. Note attenuator reading.

11. The difference between the two attenuator readings, combined with the directional-coupler loss, is the space loss.

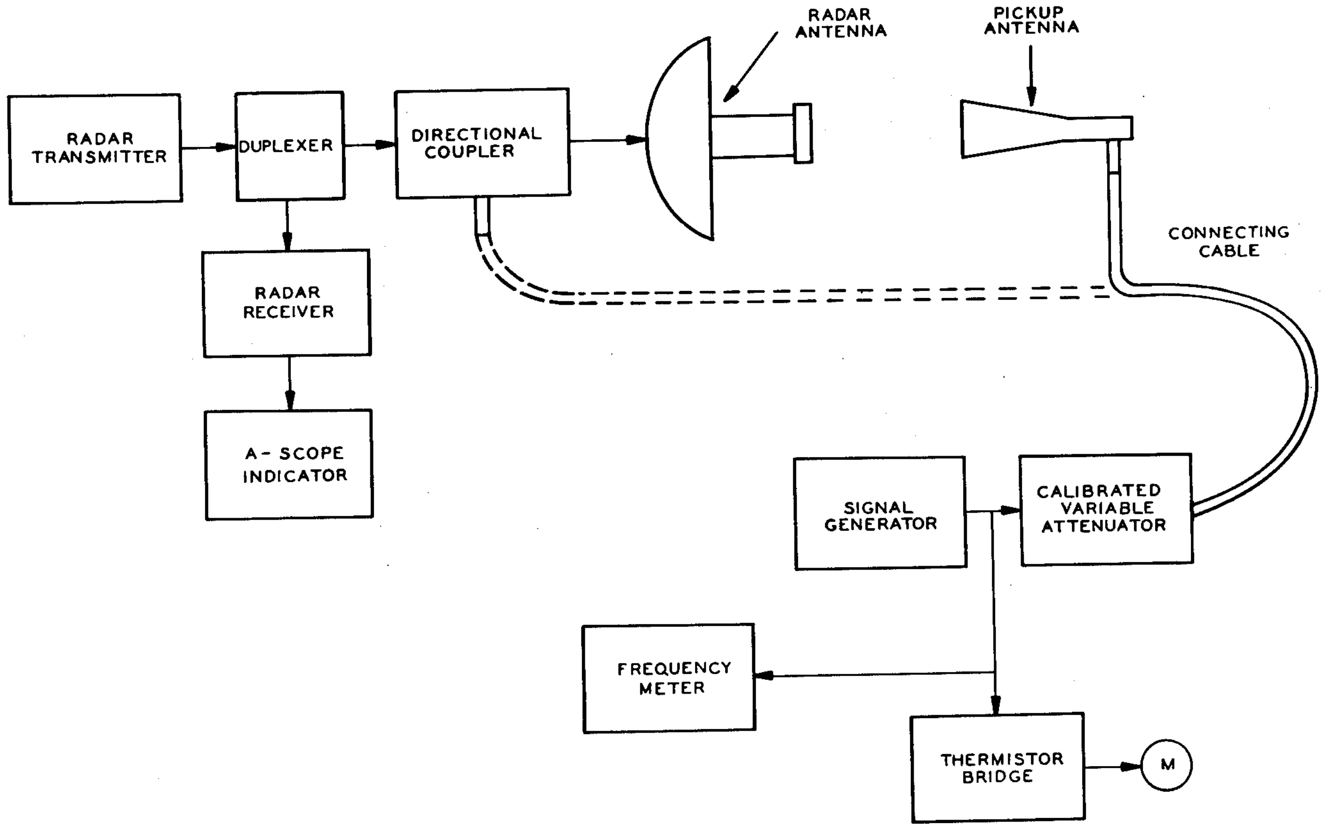


Figure 3-78. Test Setup for Pickup-Antenna Calibration—Third Method

Note

1. If readings in steps *9* and *10* are equal, the space attenuation is equal to the directional-coupler attenuation.
2. If reading in step *9* is greater than that in step *10*, space attenuation=directional-coupler attenuation + (step *9* reading — step *10* reading).
3. If reading in step *9* is less than that in step *10*, space attenuation=directional-coupler attenuation — (step *10* reading — step *9* reading).

12. Repeat the measurement at several points in the operating-frequency band, and plot a graph of space attenuation versus frequency.

(5) CABLE-ATTENUATION CALIBRATION.—During a transmitter power test, it is a simple matter to calibrate the attenuation of connecting cables. The method outlined below requires the use of an additional connecting cable, whose attenuation figure need not be known, together with a coupling adapter.

(*a*) TEST PROCEDURE.—The procedure for the test is given in the following steps:

1. Use a radar with supplied directional coupler, if possible. If a pickup antenna is used, be careful not to disturb its position while the following steps are performed.

2. Connect thermistor bridge and calibrated-attenuator type of power meter to directional coupler (or pickup antenna), by means of a connecting cable. The attenuation figure for this cable need not be known.

3. Set calibrated attenuator to give 1-mw reference power level on power meter. Note the reading.

4. Using a coupling adapter, connect cable under test in series with the cable used in step *2*.

5. Increase reading on calibrated attenuator to produce the reference level on the meter. Note the new reading.

6. The difference in the readings obtained in steps *3* and *5* is the total attenuation of the coupling adapter and the cable under test. Since the loss of the coupling adapter is usually less than .1 db, it may be ignored. Therefore, the cable attenuation is the difference in the readings obtained in steps *3* and *5*.

(6) ATTENUATOR CALIBRATION.—The method of calibrating cable attenuation just described may also be used to calibrate attenuators of both the fixed and variable types. The use of this method requires that the attenuator under calibration have cable-type fittings, or that low-loss adapters be available. Since a cutoff-type

attenuator is very nonlinear at low attenuation levels, a stop is provided to prevent operation in the non-linear region. Therefore, when the attenuator dial reads zero, there is still a fixed loss, called "attenuator zero loss". Attenuators usually are furnished with calibrated charts that give zero loss versus frequency. When an attenuator is used, the dial readings must be increased by the value indicated on the chart for the particular frequency in use. Zero loss may be calibrated by turning the dial to zero and measuring the attenuation in the same manner as cable attenuation. Each time a different frequency is used, the zero loss should be rechecked.

(*a*) TEST PROCEDURE.—Zero loss may be checked, without utilizing a second calibrated attenuator, by performing the steps given below:

1. Refer to figure 3-79 for block diagram of the test setup.

2. Proceed to calibrate a cable, which is to be used as reference, utilizing the test method described under CABLE-ATTENUATION CALIBRATION. The loss of this cable should be greater than the attenuator zero loss. If necessary, lossy cable such as RG-21/U may be used.

3. Use either an FM or pulsed-type signal generator to provide the necessary signals.

4. With the transmitter not operating, synchronize the signal generator with the same pulse used to trigger the A scope.

5. If possible, use a directional coupler to feed the signals into the radar system. An adapter or a pickup antenna may be used, but these are not as reliable.

6. Connect test setup as shown by the broken lines in figure 3-79.

7. Tune radar receiver and signal generator to the desired frequency.

8. Adjust the receiver gain to produce a pulse just a little over ½ inch high on the A scope. Reduce signal-generator output until pulse is ½ inch high, to prevent the possibility of limiting in the receiver.

9. Remove calibrating cable, and restore connections as shown by the solid lines in figure 3-79.

10. Adjust attenuator for ½ inch pulse amplitude on A scope.

11. The attenuator zero loss is the difference between the cable loss and the attenuator dial reading.

12. Repeat the above steps using at least four different frequencies in the operating band, and make a graph showing attenuation versus frequency. It can be stated generally that the attenuation increases with frequency.

3-10. RADAR TESTING—RECEIVER PERFORMANCE.

The performance of a radar receiver is determined by quite a few factors, most of which are evolved and established in the design engineering of the equipment. In the text to follow under the above title, only those factors which are concerned with maintenance will be considered. The most important factors, which will be discussed in detail, are: receiver sensitivity, which includes noise figure determination and minimum-discernible-signal

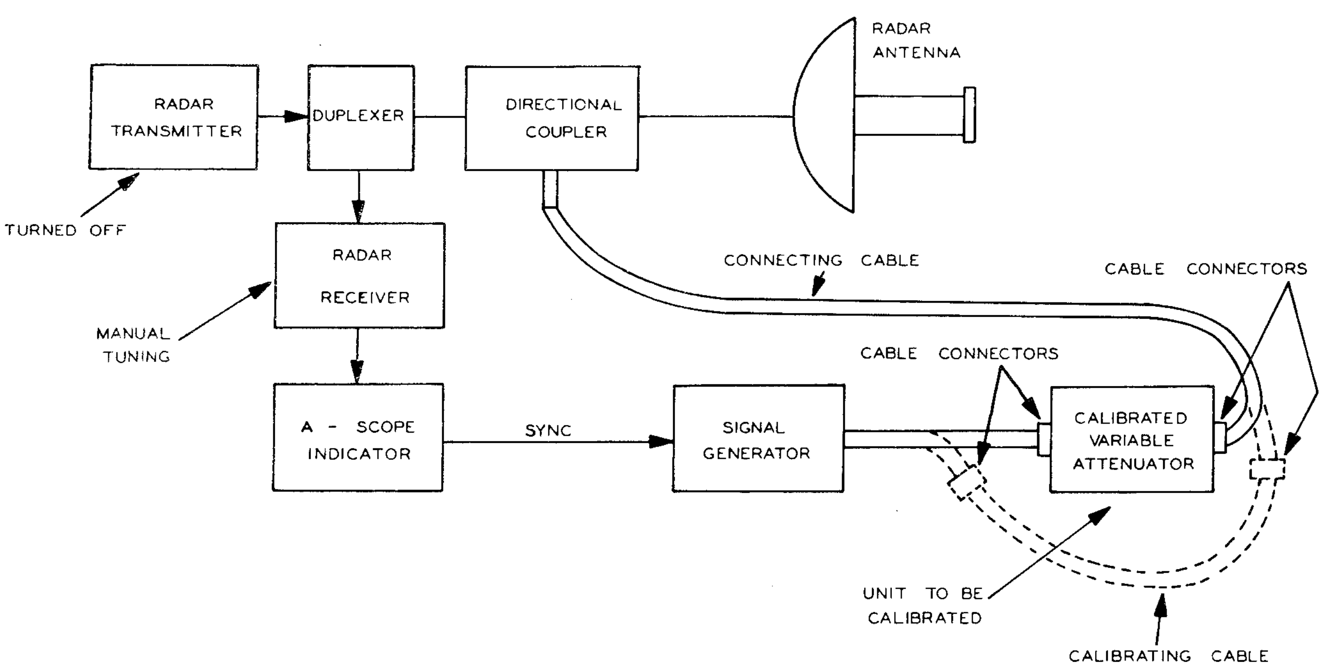


Figure 3-79. Test Setup for Attenuator-Zero-Loss Calibration

measurement; TR recovery time; receiver recovery time; and receiver bandwidth.

Many radar systems have circuits which are included to serve a special function. Four of these special circuits commonly encountered are: moving target indication (MTI), instantaneous automatic gain control (IAGC), sensitivity time control (STC), fast time constant (FTC). These circuits may be found in combination or singly depending upon the purpose of the radar. In the test methods and procedures about to be described, the special functions should be disabled. If an automatic-frequency-control (a-f-c) circuit is included in the radar, it may be permitted to operate during receiver tests. A good check on afc is to make the tests specified for manual tuning, then switch to afc. If the a-f-c circuit is normal, the signal indications should not change.

a. TESTING RECEIVER SENSITIVITY.—Inefficient range performance of a radar system can be caused by troubles in the radar receiver. This fact is brought about mainly by the greater number of adjustments and components associated with the receiver. Loss of receiver sensitivity has the same effect on range as a decrease of transmitter power. For example, a 6-db loss of receiver sensitivity shortens the effective range of a radar just as much as a 6-db decrease in transmitter power. Such a drop in transmitter power is very evident in meter indications and, therefore, is easy to detect. On the other hand, a loss in receiver sensitivity, which can easily result from a slight misadjustment in the receiver, is very difficult to detect unless accurate measurements are made. General receiver comments are available in paragraph 3-3.

The sensitivity of the receiver determines the ability of the radar to pick up weak signals. Greater sensitivity then indicates that the receiver can pick up weaker signals. Sensitivity is measured by determining the power level of the minimum discernible signal (MDS). MDS is defined as the weakest signal that produces a visible receiver output, and its value is determined by the receiver output noise level, which tends to obscure weak signals. It follows, therefore, that an MDS measurement is dependent upon the receiver noise level, and that measuring either one of these quantities will give an indication of receiver sensitivity.

(1) NOISE ANALYSIS.—In any conductor, there is a certain amount of random electron motion due to thermal agitation. This motion produces a voltage within the conductor, that varies in a random manner. Since this voltage is a pure noise voltage, it will produce signals that contain frequencies randomly distributed throughout the r-f spectrum. The signals that occur in the portion of the r-f spectrum covered by a given receiver will be picked up and appear at the receiver as noise. The input power, in watts, represented by this form of noise is given by the formula:

$$\text{Noise power} = 4KT\,\Delta F$$

Where: K=Boltsmanns' constant (1.37×10^{-23} watt-seconds per degree Kelvin)
T=Temperature in degrees absolute (Kelvin scale) $= (C^\circ + 273)$
ΔF=Range of frequencies involved (bandwidth) in cycles per second

The formula given above shows that the thermal agitation noise is determined by bandwidth and temperature. The constant merely serves to convert the noise units into units of power. A decrease of temperature causes less random electron motion and, at absolute zero, all motion and noise would theoretically cease. Since noise covers all frequencies, it is apparent that a greater bandwidth encompasses a greater range of signals, and means more noise power. In a theoretically perfect receiver, this noise could be considered as a voltage across the antenna terminals and the power represented could be calculated on the basis of temperature and bandwidth. In practice, the actual noise developed in a receiver is greater than the calculated value because of the generation of other types of noise within the receiver circuits. For example, a carbon-type resistor, which is made up of fine particles of carbon, will generate a noise signal when current flows through the resistor, because of small changes in the contact area of the particles. Various resistors have widely varying noise levels, and those that are used in the input circuits of a radar receiver must be chosen so as to have as low a noise level as possible. Electron tubes also generate noise signals, because of random variations in electron emission from the cathode, random variations in the current division between the plate and screen grid, etc. Since electron tubes produce noise in proportion to the number of electrodes employed, it follows then that triode tubes are generally used where noise limitation is an important consideration.

(2) NOISE FIGURE DETERMINATION.—The term noise figure (NF) as applied to a radar receiver, indicates the amount of noise that is to be expected. NF is defined as the ratio of measured noise to calculated noise, and may be expressed as a power ratio or in db.

In the microwave range of operation, virtually all of the noise originates within the receiver. Atmospheric and man-made noise or static is normally too small to be considered. The three main sources of noise in a radar receiver are: first, the crystal mixer; second, the i-f preamplifier (usually the first two i-f stages); and third, the local oscillator.

If the noise figure of a certain radar is too high, corrective measures must be taken. The general

procedure is given in the following discussion: First, the crystal in the radar is replaced with another one and the noise figure is rechecked. In practice, a large number of crystals may be checked by substitution, and the one with the lowest NF is used. The same procedure is then applied to the i-f preamplifier tubes. If the NF is still too high, the local oscillator tube is replaced. It is interesting to note that the output noise of a reflex klystron is much greater than normal when the tube is tuned off the center of a mode.

Early radar receivers had noise figures in excess of 20 db but modern receivers have noise figures of only 6 db to 18 db. In general, lower receiver frequencies result in lower noise figures. The noise figure of a radar receiver can be determined by the use of either a noise generator or a c-w signal generator.

(*a*) TEST METHOD USING NOISE GENERATOR.—A noise generator produces a random noise signal which covers a frequency range in excess of the radar bandwidth. One such instrument uses a temperature-limited diode, operated at saturation, as the noise-signal source. When a diode is operated under these conditions, the noise produced is proportional to the d-c input power. Therefore, the d-c input power can easily be converted to obtain the true noise power.

The procedure for determining the noise figure of a radar receiver, using a noise generator, is given in the following steps:

1. Connect a milliammeter (0—1 ma) in series with the diode load of the second detector of the receiver.

2. Ground receiver input. Adjust receiver gain to produce a .5-ma reading. This reading is due to noise alone. Remove receiver input ground connection.

3. Connect noise generator to receiver input.

4. Adjust output of noise generator until meter reads .707 ma (1.4 × .5). At this point make certain that a further increase in noise causes a corresponding increase in meter reading. If this does not happen, then the receiver is limiting and the readings will not be accurate. In this case, use a lower value of current in step *2;* for example, start with .3 ma and increase this value to .42 ma (.3 × 1.4) in step *4*.

5. The noise generator power output is now equal to the receiver noise power. Note the dial reading. A chart is usually furnished with the instrument for converting the dial reading to power.

6. Calculate the noise figure by using the following formula:

$$\text{NF (db)} = 10 \log \frac{\text{P measured}}{\text{P calculated}}$$

Where "P measured" is the amount of noise being fed to the receiver by the noise generator. This figure must be in micromicrowatts. "P calculated" is the figure arrived at by using the following formula:

$$\text{Noise power} = 4\text{KF}\,\Delta\text{F}$$

Where K is the Boltsmanns' constant (1.37×10^{-23} watt-seconds per degree Kelvin) and T is the ambient temperature of the equipment under test measured in degrees Kelvin (°C + 273) and ΔF is the receiver bandwidth (in cycles per second). As an example, to calculate the noise figure of a receiver having a bandwidth of 4 megacycles (4×10^6), and ambient temperature of the equipment in degrees centigrade being 20 (20 + 273):

$$\begin{aligned} \text{NP} &= 4\text{KT}\,\Delta\text{F} \\ &= 4 \times 1.37 \times 10^{-23} \times (20+273) \times (4 \times 10^6) \\ &= 6422.56 \times 10^{-17} \\ &= .06423 \text{ micromicrowatts} \end{aligned}$$

The measured noise power being fed to the receiver under test turns out to be 1.018 micromicrowatts. Using the formula below, the noise figure of the receiver is arrived at as follows:

$$\text{NF (db)} = 10 \log \frac{\text{P measured}}{\text{P calculated}}$$

$$\begin{aligned} \text{NF (db)} &= 10 \log \frac{1.018}{.0642} \\ &= 10 \log 15.85 \\ &= 10 \times 1.2 \\ &= 12 \text{ db} \end{aligned}$$

The noise figure for the receiver under test is calculated as 12 db, this being the normal noise figure for present-day radar receivers.

(*b*) TEST METHOD USING C-W SIGNAL GENERATOR.—The c-w method of measuring the noise figure utilizes a calibrated signal generator in the same manner as the noise generator. This method is not as accurate as the noise-generator method because the detector characteristics of the receiver under test may affect the ratio of signal power to noise power.

(3) MINIMUM DISCERNIBLE SIGNAL MEASUREMENT.—The measurement of a minimum discernible signal (MDS) consists of measuring the power of a pulse whose level is just sufficient to produce a visible receiver output. It follows that if a radar receiver has the specified MDS level, the noise figure should be correct also. Therefore, measurement of the MDS is a satisfactory substitute for a noise-figure determination, and is less complicated. Correct pulse length must be used, and when readings are taken periodically for comparison purposes, the identical pulse length must be used each time.

(*a*) R-F LEAKAGE DETERMINATION. —In the measurement of MDS, a very high de-

gree of attenuation (approximately 98 db for the average radar) and a very low power level (about one micromicrowatt) are involved. Because of these factors, very little r-f leakage from the signal generator can be tolerated, or the amount of leakage signal picked up by the receiver will be appreciable compared to the signal fed through the attenuator. Since leakage signals are independent of the attenuator setting, very inaccurate MDS readings may be obtained when leakage is present. If the leakage signal reaches the receiver in phase with the signal through the attenuator, the MDS reading will be low, and thus will indicate that the receiver sensitivity is much better than it actually is. In such a case there is a good possibility that a defective receiver may appear to be normal. On the other hand, if the leakage signal reaches the receiver out of phase with the signal through the attenuator, the MDS reading will be high, and thus will indicate that the receiver sensitivity is poorer than it actually is. In the construction of a signal generator, special attention is given to the problem of minimizing r-f leakage. The r-f oscillator is carefully shielded, and then it and the attenuator assembly are enclosed in a second shield which serves as the case of the instrument. In addition, all connecting cables and couplings are provided with shields and close-fitting connectors. In spite of these precautions, however, a small amount of leakage exists, even in the most modern equipment.

The presence of leakage makes it imperative to locate all equipment associated with MDS tests outside the radar-antenna radiation field. In addition, the equipment should never be operated outside its case, or with loose cable connections. Also, on early signal generators where a door is provided, on the front panel, for access to the oscillator adjustments, the door must be kept closed during measurements. These precautions must be observed, otherwise erroneous results will be obtained.

1. LEAKAGE DETECTION METHOD.—The presence of r-f leakage may be detected by the following method: first, determine the MDS level; second, move the test set to another position and determine the MDS level again; third, observe whether the first MDS reading differs from the second; if it does, leakage is present in one of the two positions. When leakage is found to be present, locate the test set as far from the radar antenna and receiver as possible. Find that position where movement of the test set does not affect the MDS. In general, if rotation of the test set does not change the MDS level, the r-f leakage can be considered negligible.

(*b*) EARLY METHOD USING PULSED-SIGNAL GENERATOR.—Early MDS test equipment consisted of a pulsed-type r-f signal generator, which is shown in block diagram form in figure 3-80. In this generator, the radar transmitter trigger pulse is used to trigger a start-stop multivibrator, the period of which may be adjusted to any value from about .5 to 50 microseconds. The trailing edge of the multivibrator output pulse triggers a pulse-forming amplifier, which produces a 1-microsecond pulse to modulate the r-f oscillator when the function switch is in pulse position. This modulating pulse is a positive-going pulse with a peak at zero voltage level. For c-w operation, the function switch grounds the r-f oscillator. This arrangement ensures that the peak pulse power is the same as the c-w power. The r-f oscillator is usually a reflex klystron and may be

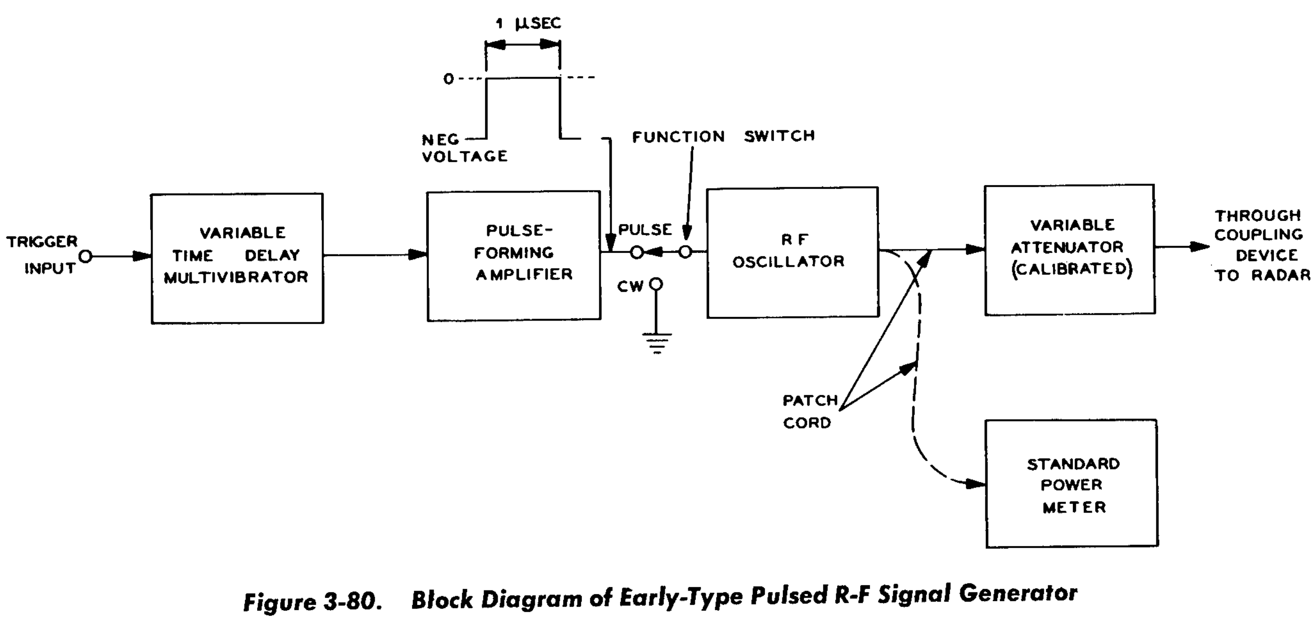


Figure 3-80. Block Diagram of Early-Type Pulsed R-F Signal Generator

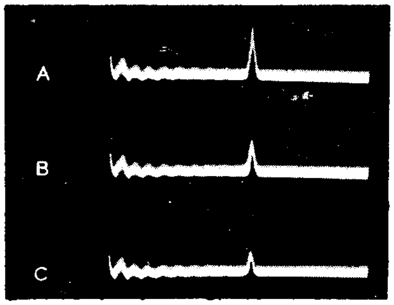


Figure 3-81. Artificial Echo Presentation on A Scope

coupled to either an attenuator or a power meter, for calibration, by means of a flexible patch cord. Early pulsed-type signal generators were coupled to the radar with a pickup antenna, but a directional coupler is more convenient and accurate. With a directional coupler, all of the power inserted into the system will be directed toward the receiver and away from the antenna. This is not true with an r-f probe. When a probe is used, half of the power is lost to the antenna.

Using the early type equipment, the procedure for making an MDS measurement is given in the following steps:

1. Connect radar trigger-pulse output to trigger input of signal generator.

2. Connect output of attenuator to pickup antenna, which should be placed as described in paragraph 3-9. *b.*(2) (*a*)*1.*

3. Set function switch to c-w position, and tune the r-f oscillator to the frequency of the radar receiver using techniques discussed in RADAR TESTING—FREQUENCY MEASUREMENTS.

4. Feed r-f oscillator output to power meter, and adjust oscillator coupling to produce standard 6-mw deflection on power meter.

5. Return patch cord to variable attenuator and set function switch to pulse.

6. Adjust receiver gain to produce a fairly large noise output (¼ inch on A scope).

7. Using a low attenuator setting, observe artificial echo pulse on radar A scope. If the radar has no A scope, connect a synchroscope to the receiver output and trigger it with the same pulse applied to the trigger input.

8. If artificial echo coincides with a target, adjust variable time delay to position the echo at a range where no targets are present.

9. Tune radar receiver for maximum echo.

10. Increase attenuation until artificial echo is just barely visible in the noise. Refer to figure 3-81. Part (A) of this figure represents a strong signal, part (B) represents the same signal attenuated 10 db, and part (C) represents the same signal attenuated an additional 5 db and approaching the MDS level. The echo pulse can be distinguished from the noise more easily during the final adjustment of the attenuator if the time delay is varied slightly.

11. Find the total attenuation by adding the attenuator reading (db), the space loss (db), the attenuator zero loss (db), and the cable loss (db).

The MDS figure is in db below 6 mw and, if desired, it may be converted to power by the use of figure 3-53. The space loss and attenuator zero loss will be the same as for a power measurement.

(*c*) MODERN METHOD USING PULSED-SIGNAL GENERATOR.—A typical, modern, pulsed-signal generator is shown in block diagram form in figure 3-82. The pulser circuit is similar to that of the older type which is shown in figure 3-80, except for the internal sync circuit. To make internal sync possible, a small part of the r-f output pulse is applied to a crystal detector,

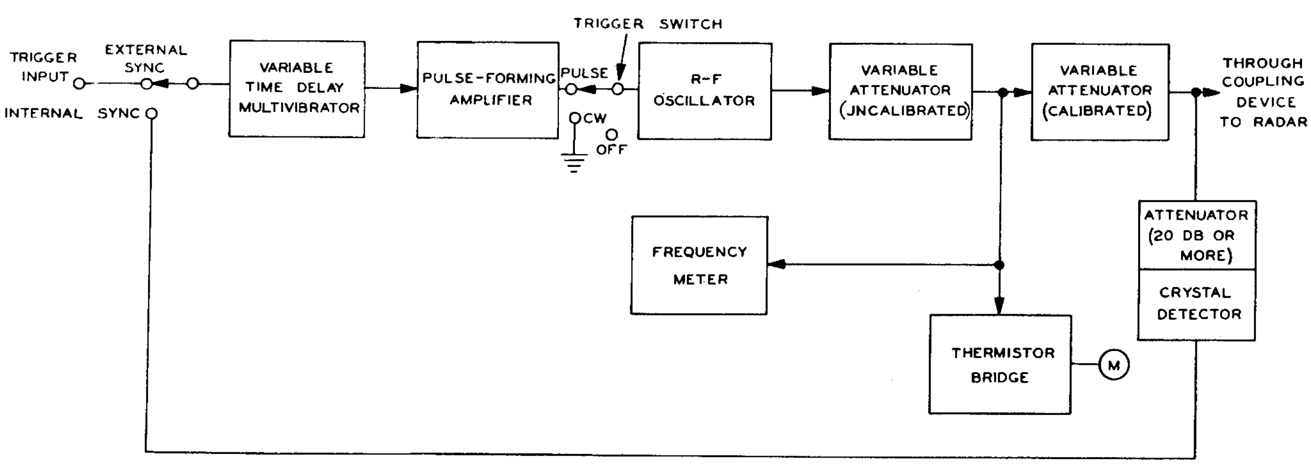


Figure 3-82. Block Diagram of Modern-Type Pulsed R-F Signal Generator

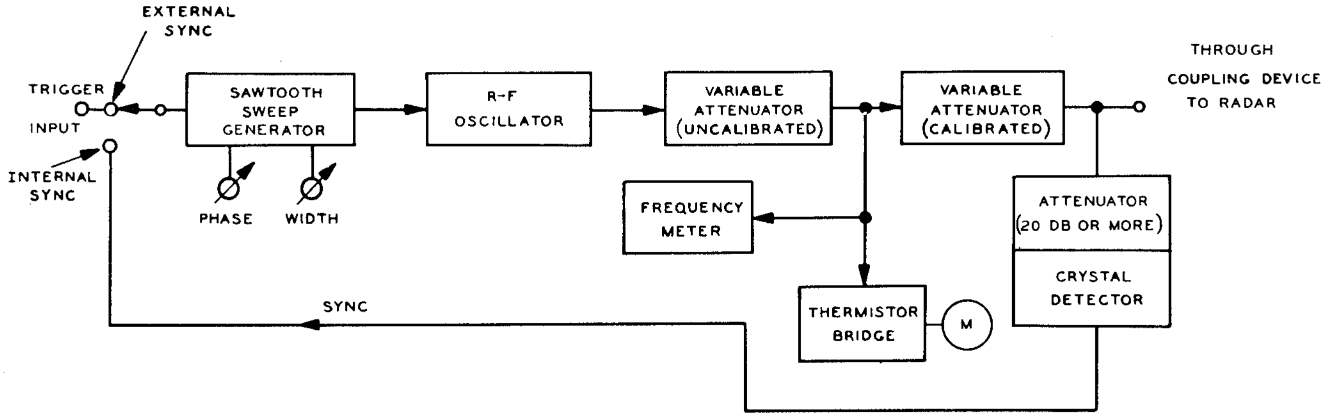


Figure 3-83. Block Diagram of FM Signal Generator Used in MDS Measurement

and the resulting rectified output signal is made available as a trigger to the pulser circuit. Thus the radar pulse can produce sync automatically, and, if desired, external sync may be used. The r-f oscillator may operate in either c-w or pulsed condition, and it may be turned off when desired. With the oscillator off, the equipment may be used to measure transmitter power and frequency. The purpose of the uncalibrated, variable attenuator, sometimes called the "power set," is to drop the output of the r-f oscillator to the standard 1-mw level used in modern test sets. The thermistor bridge monitors the power entering the calibrated attenuator. Calibration of this attenuator is such that the dial reading includes the zero loss.

An MDS measurement, using a modern pulsed signal generator, is given in the following steps:

1. If internal sync is not to be used, connect radar trigger pulse to trigger input.

2. Connect attenuator output to coupling device. A directional coupler is usually employed, but a pickup antenna may be used.

3. Set function switch to the off position and zero the thermistor bridge.

4. Turn function switch to cw and adjust uncalibrated attenuator for midscale reading on thermistor bridge.

5. Using the frequency meter, adjust the r-f oscillator to the radar frequency. The frequency meter should be kept detuned, except during frequency checks.

6. Set the uncalibrated attenuator accurately for a 1-mw bridge reading.

7. Set function switch to the pulse position.

8. Adjust the calibrated attenuator for the MDS indication previously described in the early test method. The variable time delay must be set so that the artificial echo does not occur at the same range as a radar target.

9. Find the total attenuation. The value obtained is the receiver MDS in terms of —dbm. Total attenuation = coupling loss + cable loss + attenuator reading (all in db). If desired the —dbm value may be converted into terms of power by utilizing the chart shown in figure 3-53, but the dbm reading conveys more information to the technician.

(*d*) LATEST METHOD USING FM SIGNAL GENERATOR.—When a pulsed-signal generator is used for the measurement of MDS, one major disadvantage presents itself; that is, the accuracy of the results depends upon how accurately the signal generator is tuned to the radar frequency. This difficulty has been overcome in the design of an FM signal generator incorporated in a test set as shown in figure 3-83. The r-f section of this type signal generator is very similar to that of the pulsed generator shown in figure 3-82. Since the r-f oscillator is a reflex klystron, the oscillator frequency may be varied by means of a sawtooth voltage fed to the repeller plate of the tube. This voltage is developed by a sawtooth generator, which is activated by a trigger pulse. The sawtooth voltage rise is nearly linear and lasts for about 50 microseconds. This voltage is fed to a circuit shown in basic form in figure 3-84, which contains two controls. The signal-width control determines the amplitude of the sawtooth fed to

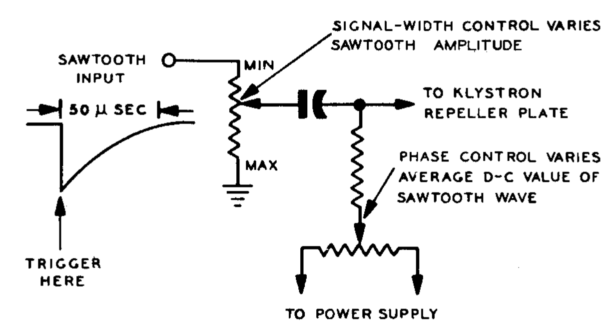


Figure 3-84. Schematic Diagram of Signal-Width and Phase-Control Circuit

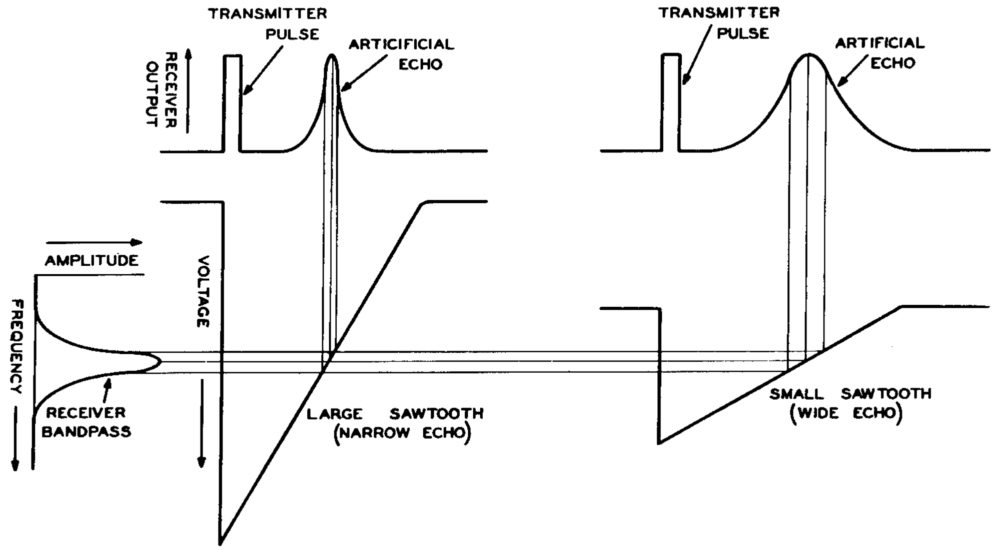


Figure 3-85. Effect of Sawtooth Amplitude on Presentation of Artificial Echo

the klystron, and the phase control determines the level of the sawtooth by supplying a variable negative d-c voltage to fix the operating point of the klystron repeller. When the signal-width control is in the maximum position, no sawtooth voltage is applied to the repeller and the signal generator supplies a c-w output. Hence, with the signal-width control in this position, the klystron mode pattern can be explored by manually varying the repeller voltage with the phase control. In operation, the FM generator creates an artificial echo pulse by rapidly sweeping an r-f signal through the receiver passband at a given time after the transmitter fires. This action is shown in figure 3-85. The transmitter pulse starts the sawtooth sweep which varies the signal frequency. As the generator frequency is swept through the receiver passband, a plot of frequency versus output is obtained, with the result that a pulse, very similar to an echo pulse, is reproduced on the radar A scope. The width of the pulse obtained depends upon the receiver bandwidth and the rate at which the frequency is swept. For example, if the receiver bandwidth is 4 mc and the klystron frequency is swept at a rate of 4 mc per microsecond, the signal will be within the frequency range of the receiver passband for only one microsecond; hence, the pulse seen on the A scope will be one microsecond wide. The effect of decreasing the amplitude of the sawtooth voltage is shown in figure 3-85. A decrease in amplitude allows the frequency to be swept at a lower rate and, thus results in a wider pulse on the A scope. By varying the signal-width control, the desired pulse width can be obtained. When measuring MDS, the pulse width is usually made equal to the transmitter pulse width; however, this is not a critical factor.

The effect of varying the phase control is shown in figure 3-86. The sawtooth waveform shown in part (B) of this figure represents a more negative average voltage. Since the sawtooth rises in a positive direction, it will take longer for the voltage level to reach the point at which the echo pulse occurs. Therefore, the average d-c voltage level determines how much time elapses between the trigger pulse and the echo pulse. Hence, the phase control is really a range control, although it is seldom labeled as such. The higher the average negative voltage, the greater the echo range. It must be remembered that each klystron mode will produce an echo indication. Therefore, by increasing the amplitude of the sawtooth voltage sufficiently with the signal-width control, it is possible to get a series of echoes, one for each mode, with the one for the most negative mode having the shortest range on the radar A scope. However, for normal operation, only one mode is used.

Using an FM signal generator, the procedure for measuring MDS is given in the steps listed below:

1. Connect radar trigger-pulse output to trigger input jack on FM signal generator. Omit this step if internal sync is to be used.

2. Connect r-f input through coupling device to radar. (A directional coupler is preferred.)

3. Set signal-width control to maximum (CW).

4. Adjust phase control for maximum klystron output as indicated on thermistor bridge.

5. Tune klystron (cavity) to approximate radar frequency, by adjusting the frequency meter to the frequency of the radar transmitter and tuning the klystron for a dip in the thermistor-bridge meter reading.

Since the klystron mode is fairly broad, extreme accuracy in tuning the klystron is not necessary. For example, the width of the flat portion

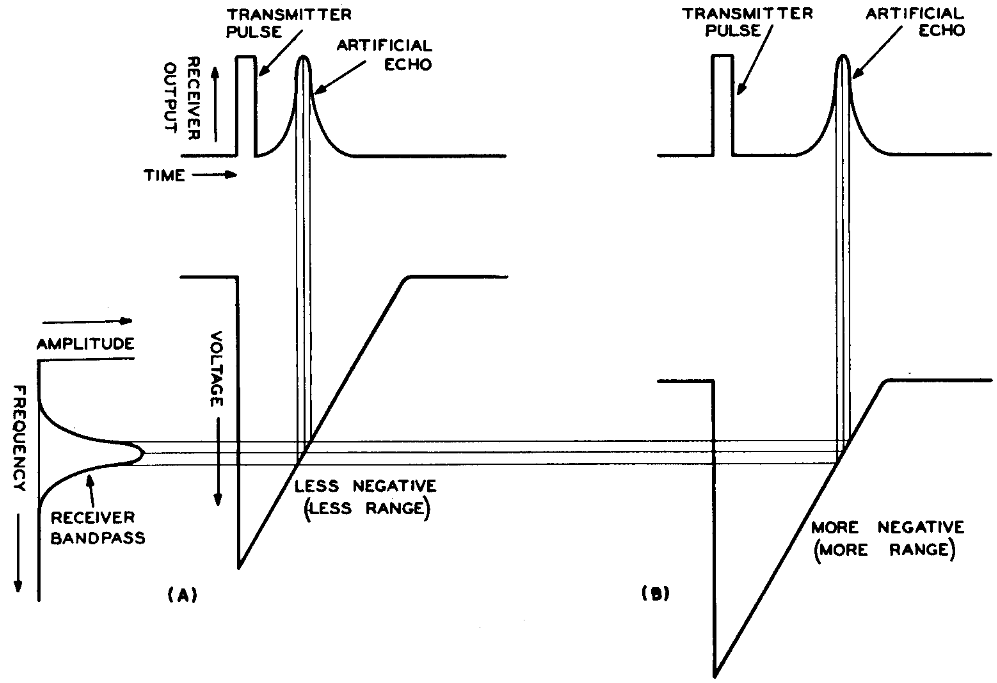


Figure 3-86. Effect of Sawtooth Level on Presentation of Artificial Echo

of an X-band klystron is about 10 mc; therefore, the tuning accuracy required is ±5 mc.

6. If necessary, adjust the phase control again for maximum output. If a sizable adjustment is required, repeat step *5*.

7. Adjust uncalibrated attenuator for a 1-mw indication.

8. Set receiver gain control for a ¼ inch noise level on the A scope.

9. Reduce signal-width control setting until the pulse is seen on the A scope. This will have to be done at a low setting on the calibrated-attenuator control.

10. If necessary, adjust phase control to position echo pulse in a target-free area.

11. Adjust signal-width control for desired echo-pulse width.

12. Set calibrated attenuator for the MDS previously described. Rock the phase control during this step to distinguish the echo more easily.

13. Find the total attenuation in db. The value obtained is the MDS in db below 1 mw (−dbm). Total attenuation = coupling loss + cable loss + attenuator reading (all in db).

b. TESTING RECEIVER BANDWIDTH.—Receiver bandwidth is defined as the frequency spread between the half-power points on the receiver response curve. Receiver bandwidth is specified for each radar, but wide variations are tolerated. If either the bandwidth or the shape of the receiver response curve is not correct, it is well to remember that a considerable change in the value of circuit components is required to alter materially the response. It is suggested that the receiver response be checked after an extensive repair to an i-f amplifier.

Figure 3-87 shows a typical response curve of a radar receiver. The half-power points are shown as 3 db below maximum (mid-frequency) response. Since the curve is plotted in terms of voltage, these points are also represented by the 70.7-percent voltage points ($\sqrt{½} = .707$) as shown in the figure.

(1) INTEGRATED RECEIVER METHOD.—The bandwidth test procedure given below is used when the receiver is operating as an integral part of the radar system, and can very easily be

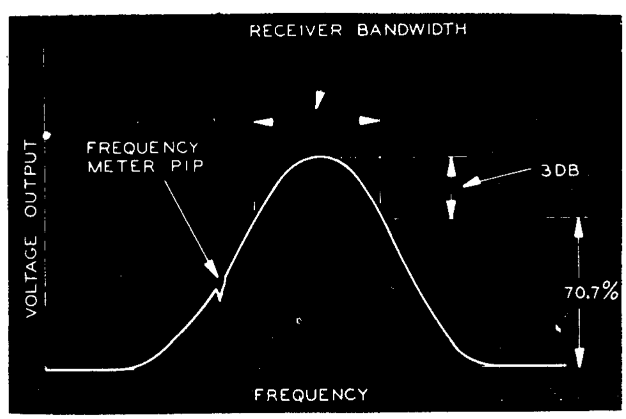


Figure 3-87. Receiver Response Curve

made after checking the MDS. When the radar receiver is to be tested as an individual component, another test procedure is used which will be described immediately following this method.

(*a*) TEST PROCEDURE.—This method, which is considered superior to other methods, makes use of the test setup for measuring MDS, using an FM signal generator as previously described in paragraph 3-10.*a*.(3) (*d*). The procedure is given in the following steps:

1. With the equipment connected in the same manner as for an MDS measurement, turn the signal-width control to obtain a response curve about one-half inch wide.

2. Reduce receiver gain so that the noise amplitude is just barely visible.

3. Adjust calibrated attenuator to produce a pulse amplitude below receiver saturation level.

4. Tune frequency meter until response curve shows an absorption pip at one of the half-power points. Read the frequency, then repeat for the other half-power point. The difference between these two frequencies is the receiver bandwidth.

(*b*) LOCATION OF HALF-POWER POINTS.—When the foregoing procedure is used, the half-power points may be located very easily as outlined in the following steps:

1. Note the attenuator dial reading following step *3* given above.

2. Increase the attenuator reading 3 db and mark the level at the top of the response curve.

3. Return the attenuator to the previous setting.

4. The half-power points are at the level marked in step *2*.

(2) DETACHED RECEIVER METHOD USING SWEEP GENERATOR.—This method is employed when the radar receiver is to be tested as an individual component rather than part of the radar system.

(*a*) TEST SETUP.—Figure 3-88 shows the test setup for checking a receiver which is

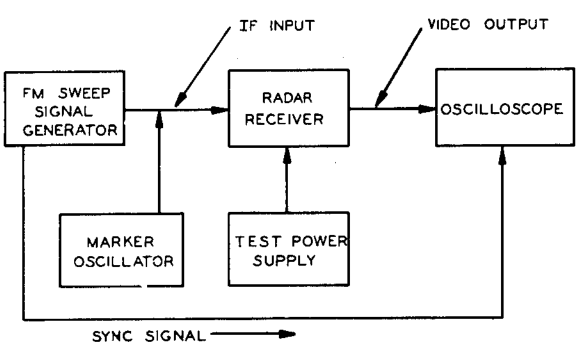


Figure 3-88. Test Setup for Checking Receiver Response

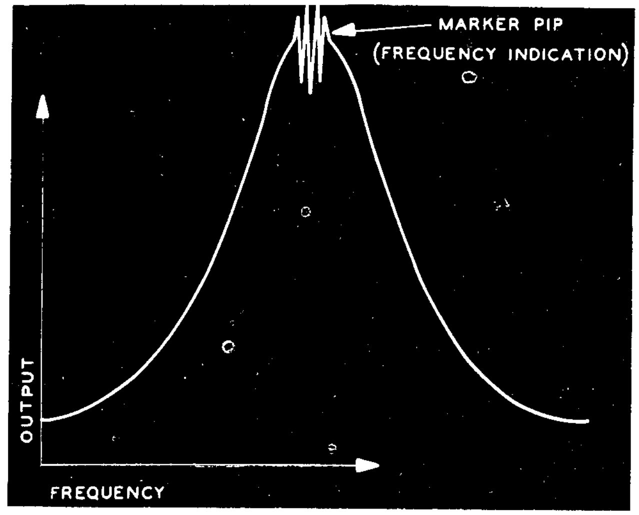


Figure 3-89. Response Curve Showing Marker Pip at Mid-Frequency Point

detached from the radar system. A sweep generator produces a variable-frequency signal that is fed into the receiver i-f input.

Note

The sweep width and the center frequency of an FM signal generator is usually adjustable to cover any standard radar intermediate frequency.

The receiver video output is fed to the vertical-deflection circuit of an oscilloscope. In addition, a sync voltage is supplied by the sweep generator to maintain horizontal motion of the electron beam in synchronism with the frequency sweep. The oscilloscope, therefore, indicates frequency horizontally and receiver output vertically. A second signal generator, called the marker oscillator, produces an accurately calibrated c-w signal which is mixed with the sweep generator output. When the varying sweep passes the marker-oscillator frequency, a beat signal results, producing a marker pip on the response curve as shown in figure 3-89. The marker-oscillator dial indicates the frequency at which the pip occurs.

(*b*) TEST PROCEDURE.—To check receiver bandwidth using the setup discussed above, the marker pip is positioned until it rests at the 70.7 percent point on the curve and the frequency dial is read. The frequency at the other half-power point is determined in the same manner. The spread between these two points, expressed in frequency, is the measured bandwidth.

c. TESTING TR RECOVERY TIME.—The time required to permit TR recovery is determined by the time it takes the TR switch to deionize after each transmitter pulse. It is usually defined as the time required for the receiver to

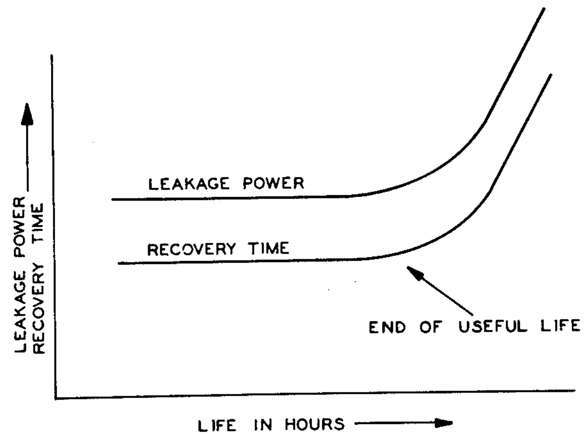


Figure 3-90. Graphic Comparison of TR Recovery Time and Leakage Power

return to within 6 db of normal sensitivity after the end of the transmitter pulse. However, some manufacturers use the time required for the sensitivity to return to within 3 db of normal or to full sensitivity. TR recovery time is the factor that limits the minimum range of a radar because the radar receiver is unable to receive signals until the TR switch is de-ionized. In various radar sets, the recovery time may vary from about 3 to 20 microseconds.

(1) TEST METHODS AND PRACTICES.—The primary function of the TR section is to protect the crystal detector from the powerful transmitter pulse. Even the best TR switches allow some power to leak through, but, when the switch is functioning properly, the leakage power is so small that it does not damage the crystal. It has been found, however, that the useful life of a TR tube is limited because the amount of leakage and the recovery time increase with use. To ensure efficient performance, some technicians make it a policy to replace the tube after a given number of hours. A better practice is to measure the TR recovery time at frequent intervals and make a graph or chart, which will immediately disclose any change in performance. Figure 3-90 shows in an approximate manner how the recovery time is correlated with leakage power. Note that the end of the useful life of the TR tube is indicated by an increase in recovery time. This method of checking the condition of a TR tube is reliable, because the recovery time increases before the leakage power becomes excessive. In practice, the TR tube is replaced when any sharp increase in recovery time becomes apparent. Ambient temperature has an effect on recovery time. The colder a TR tube, the greater is its recovery time. For example, the tube type 721A recovers in about 7 microseconds at 28 degrees (C); however, at —186 degrees (C), the recovery time is about 100 microseconds; and, at —20 degrees (C), the recovery time is about 14 microseconds. When tests are conducted under widely varying temperature conditions, this effect must be considered.

One method used in testing a TR tube is to measure the keep-alive current. This current maintains the TR tube partially ionized to make the firing more reliable, and thus helps protect the crystal. The current is usually about 100 microamperes, and falls off as the end of the TR tube life approaches. Another method is to measure the keep-alive voltage between the plate and ground of the TR tube when the voltage is known to be good, and to record this voltage for use as reference for future checks. However, these checks are not as reliable as a recovery-time test.

TR recovery time can be tested by means of a setup that utilizes either an FM or a pulsed signal generator. This method will be described in detail in the text to follow:

(*a*) TE . ROCEDURE.—Using either an FM or pulsed-signal generator, the TR recovery time test is conducted by performing the steps given below:

1. The same test setup used for the measurement of MDS is utilized for this test (figure 3-83).

2. Set receiver gain to indicate about 1/8 inch noise on A scope.

3. Adjust calibrated attenuator to give a pulse amplitude about halfway between the noise level and saturation. Note the attenuator reading.

4. Reduce attenuator setting by 6 db.

5. Rotate phase control (time delay) to position the pulse closer to the transmitter pulse. Continue rotation of control until the pulse amplitude drops to the level established in step *3*.

6. Read the range at which the pulse is now located. The value obtained is the "6 db recovery time" or the recovery time to within 6 db of normal receiver sensitivity. Recovery time may be indicated in either microseconds, miles, or yards as long as subsequent readings are in the same units.

(*b*) MODIFIED TEST PROCEDURE.—If desired, the test procedure given above can be modified so that the "full-sensitivity TR recovery time" is measured. Steps *4* and *5* are modified as follows:

4. Omit step *4*.

5. Using the phase control, move pulse toward the transmitter pulse until the pulse amplitude just starts to decrease. The use of this modified procedure will result in a longer recovery time, but when the results of a series of measurements are plotted, the curve obtained will be similar to the one shown in figure 3-90. Consistency is the most important factor; therefore, the type of recovery measurement used should always be noted in the maintenance records.

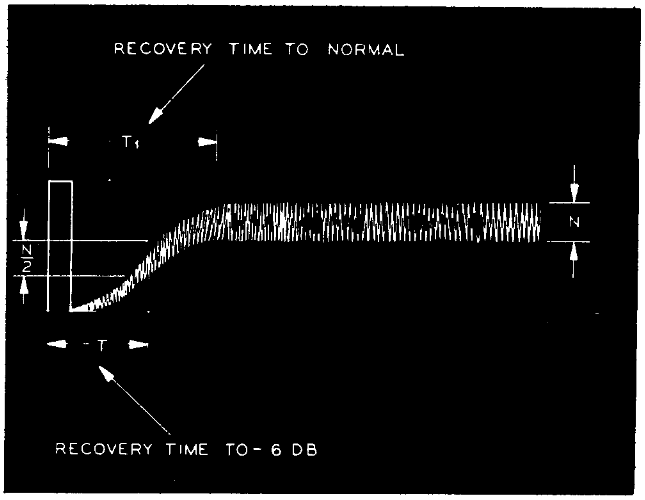


Figure 3-91. TR Recovery Test Indication Using a C-W Signal

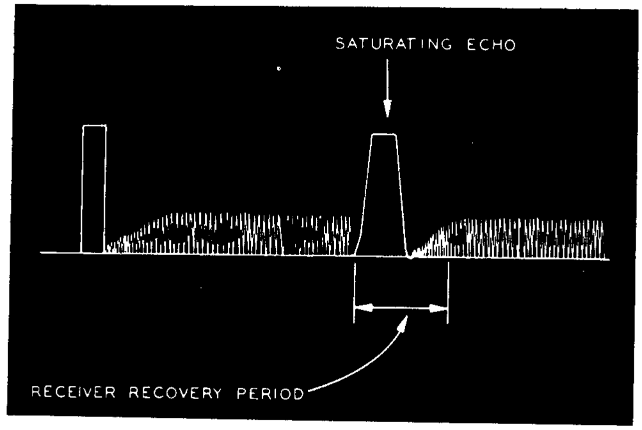


Figure 3-92. Receiver Recovery Indication

(*c*) ALTERNATE TEST PROCEDURE. —It is also possible to test TR recovery time by using a c-w signal generator. The test is conducted by performing the steps listed below:

1. Connect signal generator to coupling device.

2. Adjust radar-receiver gain to indicate about 1/4 inch of noise on A scope.

3. Tune signal generator to the frequency of the radar receiver. Proper tuning will be evidenced by a rise in the A scope trace.

4. Adjust output of signal generator (calibrated attenuator) to a point just below receiver saturation. The indication should now appear similar to that shown in figure 3-91.

5. Measure the range between the transmitter pulse and the point on the A scope where the noise amplitude is one-half of the maximum noise level.

The procedure described above gives the TR recovery time to within 6 db of normal. If the full sensitivity TR recovery time is desired, the time is measured to the point where the noise just barely reaches full value. In many cases, near-by targets will interfere with the testing of recovery time. When this occurs, position the radar antenna so as to point it at free space. In case this still does not eliminate the interference, the use of an absorption screen or a dummy r-f load is recommended.

d. TESTING RECEIVER RECOVERY TIME. —Radar-receiver recovery time is defined as the time required for the receiver sensitivity to return to normal after a saturating echo is received. This time is determined in the original radar design and is of very short duration. Receiver recovery is not discussed in terms of minimum range due to the fact that TR recovery is much longer. The receiver will recover from a transmitter pulse long before the TR tube recovers. Figure 3-92 illustrates the effect of receiver recovery. Note that immediately following the echo pulse the noise is at reduced amplitude, and that the recovery time is the period of reduced noise level. No absolute measurement of receiver recovery is necessary. A noticeable time interval, however, usually indicates trouble, which is quite often caused by an open grid-leak circuit.

3-11. RADAR TESTING—OVER-ALL SYSTEM TECHNIQUES.

As was previously discussed in the paragraph titled RADAR TESTING—GENERAL, judging the range capability and data accuracy of a radar system by visual observation alone has been found to be inaccurate and valueless. Numerous field tests made on radar sets have verified this statement. In fact, these tests disclosed that many field radars were performing at no more than one-half their maximum capability, although the maintenance and operating personnel considered the operation to be normal. Since any performance less than optimum reduces the tactical area protected by these radars, it can be seen that the measurement of performance is of the utmost importance, especially during wartime. Investigation of the above situation disclosed that many technicians are not completely familiar with the latest techniques of radar system testing. In the following text, the over-all system techniques of radar testing not previously covered are discussed. The topics included are: (1) Timing-Circuit Calibration; (2) Standing-Wave-Ratio Measurement; (3) Spectrum Analysis; and (4) Over-all System Performance.

a. TIMING-CIRCUIT CALIBRATION. — Although pulsed radar systems were developed primarily for the detection and ranging of various objects, certain specialized requirements have entered into later applications. Each radar is designed for a particular job which requires the utilization of the information and data supplied

by the system. Radar systems may be classified as to the particular use that is made of the data supplied. Any radar system may be said to perform one or more of the following functions: (1) Search —location of targets with respect to the position of the radar (this may include IFF applications); (2) Navigation—location of the radar with respect to targets or beacon stations; (3) Ground Control—control of aircraft and direction of air traffic (blind landings and fighter direction); (4) Fire Control—aiming of guns controlled by radar information; (5) Intercept—directing fighters toward enemy and, if necessary, enabling blind firing; (6) Bombing—providing information that enables bombers to locate and destroy targets under blind conditions.

Of the six functions just mentioned, all except search require extremely high range accuracy. Therefore, in all radars except those used for search, it is very important for the timing circuits to be accurately calibrated.

(1) RANGE MEASUREMENT. — A block diagram of a typical radar ranging system is shown in figure 3-93. The system trigger generator supplies the pulse required to drive the modulator and also to initiate the action of the range-marker generator. This generator produces an output pulse at some time after the occurrence of the system trigger. The exact time difference is dependent upon the time delay introduced. Range is determined when the operator sets the range control to a point where the range pulse coincides with the target whose range is to be measured. The range in miles or yards is then read from the dial. In those radar systems used for fire control or bombing, the dial may be mechanically connected to a computer.

(2) DATA ACCURACY.—Since the range of a target is determined by the time interval between the transmitted pulse and the echo return, all time delays introduced by the radar-system components will add to the range indication, so that the range indicated will be in error by an amount equivalent to the time delays which have been introduced.

(*a*) TIME DELAYS—ZERO ERROR.—In every radar system, there are time delays which occur within the equipment between the time the system trigger is initiated and the time the echo pulse arrives at the indicator. The causes of these time delays are as follows: (1) The modulator output pulse occurs a short time after the trigger input pulse; (2) the r-f output from the transmitter takes time to increase to the proper amplitude after application of the modulator pulse; (3) time is required for the transmitter r-f energy to travel to the antenna, and also for the reflected r-f energy to travel from the antenna to the receiver; (4) time is required for the r-f pulse to travel through the receiver (this cause is responsible for the greatest time delay).

The delays listed above, when combined, may represent a range of 150 to 350 yards. This means that a target actually at zero range would be erroneously indicated at a range of 150 to 350 yards. Thus, it is seen that this zero error seriously affects the accuracy of all range measurements. For example, a target at a distance of 1000 yards would be indicated at a range of 1150 to 1350 yards. Since the zero error represents a fixed quantity for any individual system, it is the same at all ranges.

(3) DETERMINATION OF ZERO ERROR.—Before the effect of zero error can be corrected, it is necessary to determine how much time delay is present in a given system. There are four methods which could be used in making this measurement, the fixed-target, the double-echo, the external range-calibrator, and the synchroscope methods.

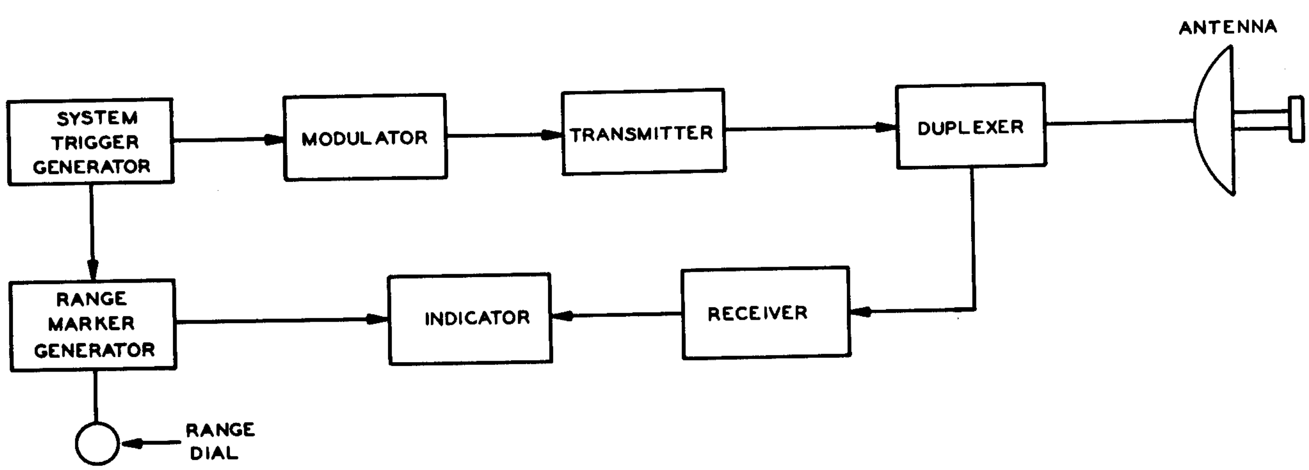


Figure 3-93. Block Diagram of a Typical Radar Ranging System

(*a*) FIXED-TARGET METHOD. — The fixed-target method of zero-error determination is the most reliable method in common use. This method involves the use of a fixed target at some accurately known distance. A natural target may be used, but a portable reflector will give more reliable results. The target range indicated by the radar system is carefully read and compared with the known range. The range indicated by the radar should be greater than the known distance, and the difference is the zero error.

(*b*) DOUBLE-ECHO METHOD. — The double-echo method of range correction is normally associated with fire-control radar equipments, but any radar set that is capable of receiving two echoes from the same target during one sweep on the range scope is capable of determining range accuracy by the double-echo method. An example of how the double-echo method can be used aboard ship is given below.

1. The radar antenna should be trained on a target, preferably a large ship steaming abeam the radar ship and on an identical course and speed, and at a range of between 1000 and 3000 yards. A transmitted radar pulse strikes the target ship, is reflected, and returns to the point of transmission. A small portion of this returned radar pulse is accepted by the radar antenna and presented as target "A," figure 3-94, on the indicator of the radar equipment. The remainder of the returned pulse is re-radiated by the steel hull of the radar ship and is directed back toward the target ship for the second time. There the radar antenna accepts the pulse and presents it as target "B."

2. The time elapsed between the reception of target "A" and target "B" indicates the true range of the target ship from the radar ship, provided of course that both targets were received during the time of one sweep of the range scope. By placing the ranging device (step, notch, or marker) at target "B" and noting range "d," and then moving the ranging device to target "A" and noting range "c," the correct range may be computed. Subtract the range recorded for target "A" from the range recorded for target "B" ("d" minus "c"). This resultant figure should equal the range recorded for target "A." If it does not, then with the ranging device at target "A," the range correction control should be adjusted, or the range counter mechanically disengaged and "slipped" until the counters indicate the correct range. This procedure of noting the ranges and altering the counters should be repeated as many times as necessary to obtain accurate ranging. One note of caution should be observed—the measurement of ranges "c" and "d" should be made as quickly as practicable, to prevent the possibility of the target range varying by any appreciable amount during the time interval between two range measurements.

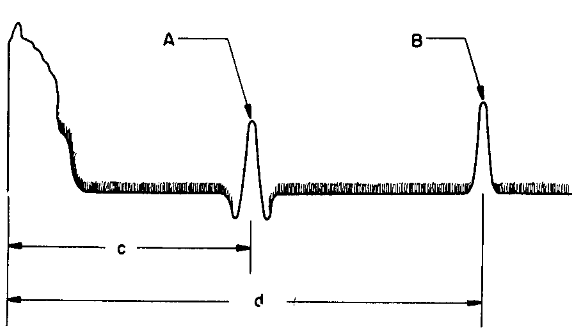


Figure 3-94. Double-Echo Range Scope Presentation

(*c*) EXTERNAL RANGE-CALIBRATOR METHOD.—Various test equipments are available for calibrating radar range units, e.g., Range Calibrators TS-358/UP or AN/UPM-11. These units function basically in the same manner. They provide crystal-controlled calibration markers for checking and adjusting the calibration circuits of the unit under test. The range calibrator also provides a synchronizing pulse input to the calibration circuit under test. The timing of this triggering pulse may be varied in order to synchronize the occurrence of markers on the range indicator with the marker generated by the range calibrator. The manner in which a range calibrator can be employed is as follows:

1. Connect the 50-MILE marker output of Range Calibrator TS-358/UP to the input of the first marker amplifier of the range indicator. Connect the TRIGGER output of the range calibrator to the range indicator trigger input jack or terminals. Energize the radar indicator, and adjust the horizontal and vertical centering controls for proper positioning of the range sweep. Set the range indicator to operate on the 200-mile scale.

2. Adjust the range calibrator TRIGGER DELAY control until the first marker aligns with the start of the range sweep. Four markers should appear as vertical pips on the range sweep, and should coincide with range marks inscribed on the tube face or with the ranging device provided (step, notch, etc). If they do not, then alignment of the circuits should be made utilizing the adjustments provided, such as sweep rate or gate length controls.

(*d*) SYNCHROSCOPE METHOD. — The synchroscope method of measuring zero error does not require the use of a fixed target, and gives fairly accurate results. Figure 3-95 shows the test setup for this method. The synchroscope sweep is triggered by the radar system trigger. A fast sweep (about 2 microseconds per inch) is used, and is carefully calibrated in the number of microseconds each inch of sweep represents. If the sweep is linear, any portion of the trace may

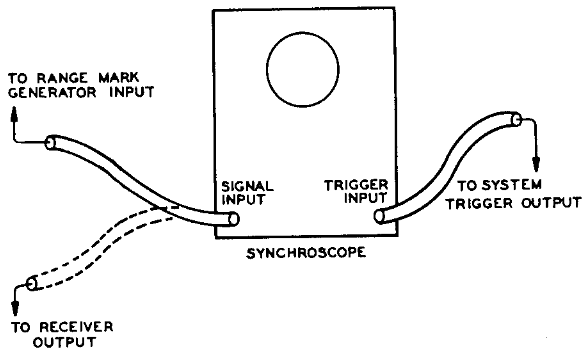


Figure 3-95. Test Setup for Synchroscope Method of Zero-Error Determination

be used. To determine zero error by this method, proceed as follows:

1. Use radar-system trigger pulse to provide external sync for the synchroscope.

2. Calibrate sweep speed of the scope to represent about 2 microseconds per inch.

3. Feed the trigger pulse which starts the range-marker circuit into the vertical amplifier, and set the scope gain to provide a ½ inch pulse.

4. Carefully mark the leading edge of the pulse on the scope.

5. Remove the trigger pulse and feed the radar-receiver output to the vertical amplifier. Note: The radar local oscillator should be detuned; the transmitter pulse shock-excites the r-f preamplifier sufficiently to produce an i-f signal.

6. Adjust the scope gain to provide a ½ inch pulse when the receiver gain is set to produce about ⅛ inch of noise.

7. Carefully mark the leading edge of the pulse on the scope, in the same manner as was done in step *4*.

8. Measure the distance between the two marks on the scope. Note: the pulse in step *7* should occur later than the pulse in step *4*.

9. Convert the distance between pulses to microseconds and, then, if desired, into yards. This figure is the zero error.

Note

The above method of measuring zero error involves the use of a synchroscope having a fixed, internal time delay (AN/USM-24). It should be noted that this delay is present in the readings taken in both step *4* and step *7*; therefore, both pulses are delayed by the same amount, thus eliminating the effect of the test equipment internal delay.

(4) ZERO-ERROR CORRECTION—MARKER COMPENSATION.—After the zero error of a radar system is measured, compensation is made in the range-marker circuit. In most cases, calibration is carried out at two different points in the delay range. If a given radar has a 200-yard zero error and a 12,000-yard range-marker circuit, and the calibration points are at 1000 yards and 10,000 yards, the 1000-yd point should be set up at 800 yards and the 10,000-yd point should be set up at 9,800 yards. After compensation, the zero error should be measured again, to make sure that it has been reduced to zero yards.

The zero-error figure for a given radar is a fixed characteristic. However, it can change if components are damaged or replaced. For this reason, the zero error should be measured after each overhaul or repair job.

b. STANDING-WAVE-RATIO MEASUREMENT.—In any pulsed radar system, the function of a transmission line or waveguide is to transfer r-f power alternately from the transmitter to the antenna, and then from the antenna to the receiver. During that part of the cycle when transmission occurs, the magnetron oscillator acts as a generator, with the antenna as the load, while the duplexer isolates the receiver from the transmitting system. When reception takes place, the antenna is considered the generator, with the crystal mixer as the load, while the ATR switch isolates the magnetron from the receiving system.

During transmission, if any mismatch or line discontinuity exists, power reflections will occur. When reflections are present, the combination of incident and reflected power produces a fixed pattern is dependent upon the percentage of reflected tion 2, figure 2-63, and is discussed in paragraph 2-10.*a.* The amplitude of the standing-wave pattern is dependent upon the percentage of reflected power, which is determined by the degree of mismatch or reflection coefficient. Standing-wave amplitude is measured in terms of standing-wave ratio (SWR). The standing-wave ratio is usually given in terms of VSWR, or voltage standing-wave ratio. The voltage standing-wave ratio is equal to the square root of the power standing-wave ratio, as shown by the following equation: $VSWR = \sqrt{PSWR}$, and conversely, $PSWR = (VSWR)^2$.

(1) UTILITY OF SWR MEASUREMENT.—In a radar system a low SWR is maintained principally for the following reasons: (1) Reflections occurring in the r-f line cause magnetron pulling, and may result in faulty pulsing (this effect is more pronounced when the line is long, as compared to a wavelength); (2) arc-over may occur in the r-f line at maximum voltage points; (3) mechanical breakdown in the line may sometimes occur, due to the development of hot spots.

To prevent magnetron pulling, the VSWR should be less than 1.5 to 1, which represents a reflection of less than 5 percent of the incident power.

In the maintenance of radar systems, SWR measurements are useful in two ways. First, defective r-f line components may be located by

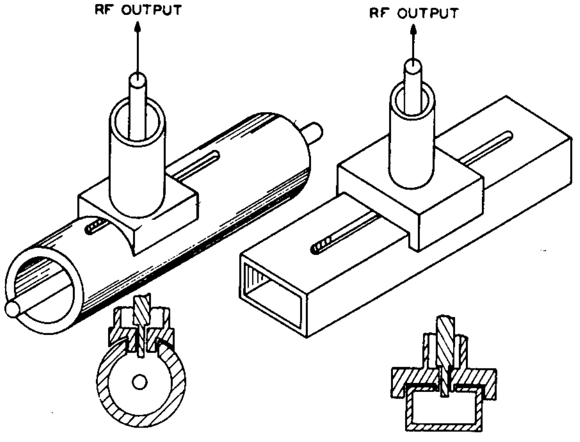


Figure 3-96. Slotted-Line Sections, Showing Probe Location and R-F Output

checking the SWR of each component or by substitution. Second, radar systems having r-f tuning adjustments may be adjusted with the aid of SWR test equipment.

(2) SLOTTED-LINE METHOD.—The slotted-line method of measuring SWR can be used with the aid of an r-f probe and a slotted line. The slotted line is a coaxial or waveguide section of transmission line, with a longitudinal slot cut into its outer conductor, which permits insertion of the r-f probe. This is shown in figure 3-96. The slot is constructed at least a wavelength long, and is not wide enough to cause appreciable loss by radiation. In order to explore the voltage field existing in the line, the probe is placed in the electrostatic field through the slot and moved back and forth. The probe feeds an r-f detector, and the rectified output operates a meter which indicates the VSWR.

Many radars have slotted-line test sections that are integral parts of the r-f system. In such cases, a protective plate which is removable usually covers the slot, and allows the line to be pressurized. For those systems not having the built-in slotted sections, a series of slotted-line sections that will fit any radar have been devised. In some cases the section is inserted into the radar system by means

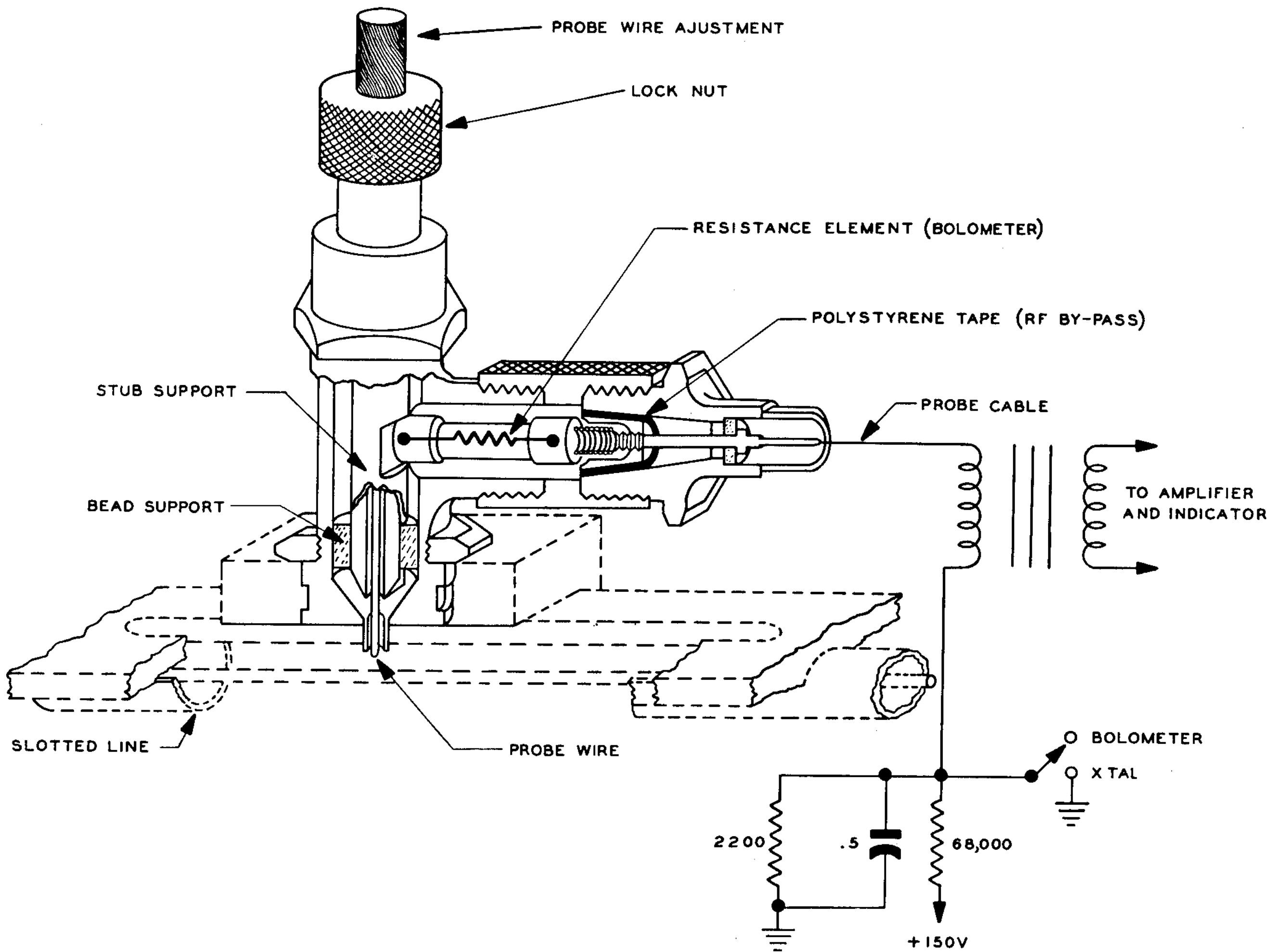


Figure 3-97. Typical R-F Probe, Showing Construction and Associated Test Circuit

of coupling sections, or a test setup is developed whereby the radar units may be tested. Figure 3-42 shows a typical built-in slotted-line section.

(*a*) R-F PROBE.—The construction of a typical r-f probe is shown in figure 3-97, along with the associated test circuit for VSWR measurement. The probe wire is adjustable for depth of penetration (coupling), so that the amount of r-f pickup can be controlled. In practice, the coupling is maintained at a minimum, to prevent distortion of the fields inside the r-f line. The r-f detector shown in figure 3-97 is a type of bolometer called a barretter, and consists of a fine resistance wire, which presents a matched load to the r-f probe. Refer to paragraph 3-5.*c*.(3) for a discussion concerning the barretter. A direct current is passed through the resistance wire, and the current value is altered by the r-f energy, which heats the wire, thus changing its resistance. R-F pulses will cause corresponding pulses of current flow, which are amplified, rectified, and fed to an indicating meter calibrated to read VSWR directly. A crystal rectifier, such as a 1N21 or 1N23, may be used in place of the barretter, in which case no direct current is necessary.

(*b*) TEST PROCEDURE. — VSWR is measured by performing the steps given below:

1. If the radar system has no built-in slotted line, insert a slotted section into the radar transmission line (with the adapters provided), as close to the magnetron as possible.

2. Connect r-f probe to amplifier, and adjust probe for a penetration of a few thousandths of an inch.

3. Operate radar transmitter and move probe to a maximum point.

4. Set probe penetration to provide a ¾-scale meter reading.

5. Move probe to a minimum point, and read VSWR on meter.

6. If VSWR is too high (1.5 to 1 or higher) and the radar has tuning stubs, adjust the stubs for a VSWR of as near 1:1 as possible. The latter adjustment should be made with the antenna pointing at free space.

(3) SPECIAL METHODS.—In addition to the slotted-line method of SWR measurement discussed above, there are two other methods, the directional-coupler and the magic-tee methods, which are described below:

(*a*) DIRECTIONAL-COUPLER METHOD.—The directional-coupler method of determining VSWR is frequently used in the field. To determine the SWR of an r-f system, the coupler is inserted into the system and the incident power is measured. The coupler is then reversed, and the reflected power is measured. The SWR can then be calculated. This method is not very accurate if the coupler directivity is low. For example,

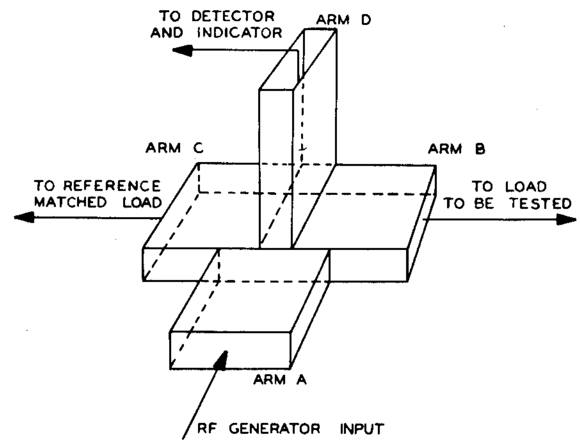


Figure 3-98. Magic Tee

if a given coupler has a nominal loss of 20 db and a directivity of 20 db, the VSWR obtained as a result of its use is 1.6 to 1; however, the actual VSWR may be any value from 1.4:1 to 1.8:1. It is seen, then, that the greater the directivity, the greater the accuracy.

The above method has been largely superseded by the use of the bi-directional coupler, which greatly simplifies the application. This type of coupler, which consists of two directional couplers mounted on the same line, coupling in opposite directions, has been developed to a point where the accuracy of the method is quite good. The bi-directional coupler does not require reversing, is easier to use than the slotted line, is more rapid in operation, and can be made a permanent part of a pressurized r-f system. In addition, the coupler may be used in connection with power and frequency testing and spectrum analysis, which is discussed in detail following standing-wave-ratio measurement.

(*b*) MAGIC-TEE METHOD.—A special form of directional coupler called the "Magic Tee," which is illustrated in figure 3-98, may also be used for SWR measurements. The magic tee type of coupler consists of four waveguides joined together as shown in the above figure. The important consideration in this type of coupler is that the polarization of arm D is at right angles to that of arm A, so that there is no direct coupling between arm A and arm D. However, it should be noted that arm A couples to both arm B and arm C, and that arm D also couples to both arm B and arm C. Therefore, power is coupled from arm A to arm D only when reflections are produced in arm B or arm C.

1. TEST SETUP AND PROCEDURE. —A signal generator is connected to arm A through an isolating attenuator which provides an impedance match to this arm. A matched load, similar to that shown in figure 3-99, is connected to arm C. The device under test is connected to arm B. An r-f detector is connected to arm D, and

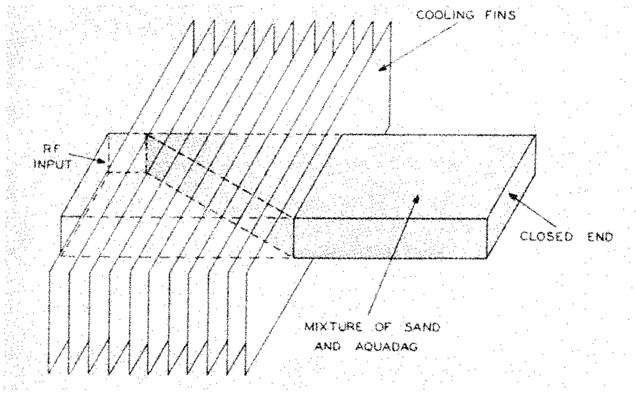


Figure 3-99. Typical Waveguide-Type Dummy Load

provides an impedance match to that arm. In operation, power enters arm A, dividing between arm B and arm C. No power is coupled to arm D. In arm C, the matched load absorbs all the incident power coupled in that direction. If the device under test causes no reflection, all the incident power flowing to arm B is absorbed. When this condition prevails, the detector in arm D indicates zero. However, if the device connected to arm B is not matched, some of the incident power is reflected. The amount of reflected power is a function of the degree of mismatch. The reflected power is returned to the junction of the arms, and a portion is coupled to arm D. Thus, any power in arm D indicates a mismatch at arm B, and the SWR may be evaluated in terms of the power in arm A, as compared to the power in arm D.

(4) CAUSES OF STANDING WAVES—DISCONTINUITIES.—Any discontinuous change along an r-f line, such as might be introduced by a change in dimensions, or a change in geometry introduced by a sharp bend or dent, or an obstacle in the line, will produce reflections. Some of the most common causes of an excessively high standing-wave ratio are: (1) Dirt or moisture in the r-f line; (2) dented or bent line; (3) burrs or poorly soldered joints; (4) defective coupling joint; (5) defective rotating joint; and (6) mismatched antenna.

(5) LOCATING DISCONTINUITIES.—If an increase is noted in the standing-wave ratio, check the r-f transmission lines for the common causes listed above, and for any other damage which might occur as a result of battle, storms, or normal wear. Check the antenna also, since any bending of the reflector or dipoles would change its impedance and result in an increased SWR.

Many r-f transmission-line faults are visible and easily located; however, in some cases the trouble may be of such a nature that the defective part can be found only by making special tests.

(*a*) DUMMY R-F LOADS.—A dummy r-f load is a resistive section of transmission line which will absorb r-f power without causing reflection. Figure 3-99 shows the construction of a typical waveguide-type dummy load. This particular type of dummy load utilizes a section of waveguide which is filled with a mixture of sand and Aquadag that serves as a resistance to absorb power. In order to minimize reflections, the front surface of the resistance element is constructed so as to present an oblique surface to the incident r-f power. The exterior of the dummy load is fitted with cooling fins, and is painted a dull black for greater heat transfer. A typical X-band load will give a VSWR of less than 1.05 to 1, and will absorb 150 watts of power (average). If necessary, the power rating of dummy r-f loads can be increased by the use of forced air or water cooling.

Coaxial dummy r-f loads are similar in operation to the waveguide-type loads. The resistive mixture forms a tapered contact between the inner and outer conductors.

Two distinct advantages are gained by the use of dummy r-f loads in radar maintenance: (1) Where military security prohibits r-f radiation, maintenance may still be carried out with the aid of the load; and (2) the load may be used to absorb power without reflections, regardless of surroundings; it may also be used for measurement of power output.

(*b*) TEST METHOD USING DUMMY R-F LOAD.—When the SWR of an r-f transmission line becomes excessive, the cause of the standing waves may be located with the aid of a dummy r-f load by performing the steps given below:

1. Remove antenna feed, and substitute dummy r-f load. If the substitution corrects the condition, the trouble may possibly be in the antenna, or it may be due to reflections from near-by objects.

2. If the VSWR is still too high, change the antenna scanning position and recheck the VSWR. If the VSWR changes, a defective rotating joint is sometimes indicated. In some cases, the VSWR may not change, even though a rotating joint is defective. Therefore, this test will not eliminate the possibility of a bad joint, but will locate faults due to rotation.

3. If the rotating joints do not check defective, remove the section of line next to the antenna feed section, and replace the dummy load at the open end of the r-f system. Recheck the VSWR. If the section removed is defective, the VSWR will improve. Continue the process of removing sections until the offending section is located. The VSWR should be checked again after the trouble is corrected and the r-f components are reassembled.

(*c*) TEST METHOD FOR COMPONENT CHECKING.—A test method utilizing the VSWR, which is used for checking r-f transmission-line components, is described in section 2, paragraph

2-10.*b*.(1). Figure 2-64 illustrates the test setup for the above check.

c. SPECTRUM ANALYSIS.—It is possible, by means of a test equipment called a spectrum analyzer, to observe on the screen of a cathode-ray tube a selected portion of the electromagnetic spectrum. The display consists of vertical pulses distributed along the horizontal axis; the position of each pulse indicates the frequency of a particular signal, while the relative height of each pulse indicates the relative strength of the signal. In other words, the display viewed on the cathode-ray-tube screen is, in effect, a graph of energy plotted against frequency.

By analyzing the spectral display of a radar transmitter, a great deal of information may be obtained. The spectrum analyzer can show the presence or absence of frequency modulation, and can also indicate the presence or absence of amplitude modulation in the signal. By means of a frequency meter, which is normally an integral part of the spectrum analyzer, it is possible to determine the bandwidth necessary to transmit each signal. The built-in frequency meter may also be used to check local-oscillator frequencies and retune receivers. If frequency pulling is present, the shift of the observed spectrum relative to the frequency-meter pip can also be noted. To summarize, spectrum analysis provides information regarding the condition of a radar. Incorrect spectral displays can indicate: (1) magnetron pulling; (2) magnetron pushing; (3) magnetron double-moding, mode shifting, and mode jumping; and (4) improper pulse width. In addition to the items mentioned above, indications of transmitter and local-oscillator frequencies are available which facilitate local-oscillator tune-up and a-f-c testing.

(1) COROLLARY TESTING DATA.—The following information is provided for the technician as pertinent to the analysis of spectral displays. Information concerning the characteristics of sine and square waves is covered.

(*a*) SINE-WAVE SPECTRAL DISPLAY.—For purposes of discussion, a pure sine wave can be considered to represent a single frequency. The spectral display of this waveform is shown graphically in part (A) of figure 3-100 as a single vertical line designated as F_o. The height of the line represents the power contained in the single frequency. Part (B) of figure 3-100 shows the spectral display for a single sine-wave frequency (F_o) modulated by another sine wave (F_1). In the latter case, two sidebands are formed, one above and one below the carrier frequency represented by F_o, corresponding to the sum and difference frequencies. When additional modulating frequencies are used, two sidebands are added for each frequency.

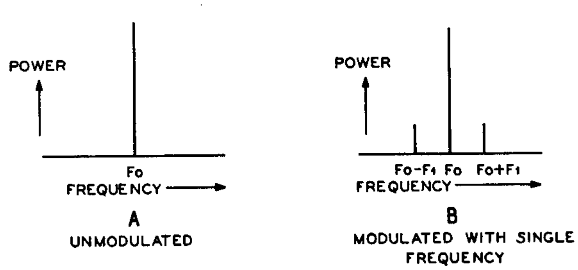


Figure 3-100. Sine-Wave Spectral Displays

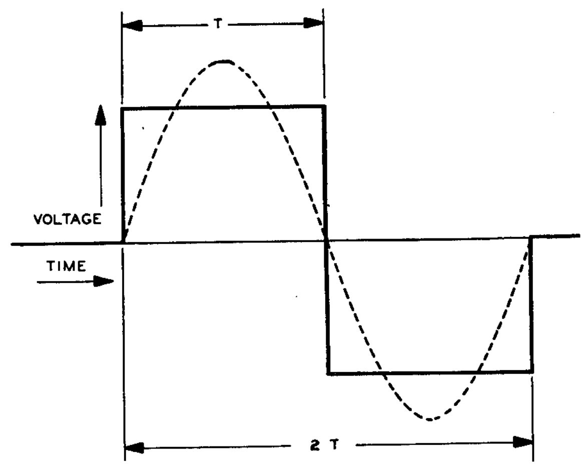


Figure 3-101. Rectangular Pulse, Showing Fundamental Sine-Wave Component

(*b*) SQUARE-WAVE ANALYSIS.—A perfect square wave may be considered to consist of a fundamental sine wave plus an infinite number of odd-harmonic, in-phase sine waves which progressively decrease in amplitude as the harmonic number increases. Theoretically, therefore, a 100-c-p-s square wave would contain frequencies of 100 cps, 300 cps, 500 cps, 700 cps, etc, to infinity. Since a perfect square wave represents an ideal condition, only a limited number of harmonics are involved in the usual square wave. However, a good square wave may contain frequencies up to the 100th harmonic in practical cases.

Figure 3-101 shows the relationship existing between a rectangular pulse and its fundamental sine-wave component. The width of the pulse is represented by t, and the period of the sine wave by 2t. Therefore, the fundamental sine-wave frequency, or the fundamental pulse frequency, as it is usually called, is 1/2t. Any harmonic of this frequency can be determined, in terms of t, by multiplying the expression 1/2t by the number of the harmonic. For example, the second harmonic is 2(1/2t), or 1/t.

(2) TRANSMITTER SPECTRAL DISPLAY.—When a transmitter is modulated by short rectangular pulses occurring at the PRF (pulse repetition frequency) of the radar, two distinct modulating components are present: (1) That component consisting of the PRF and its as-

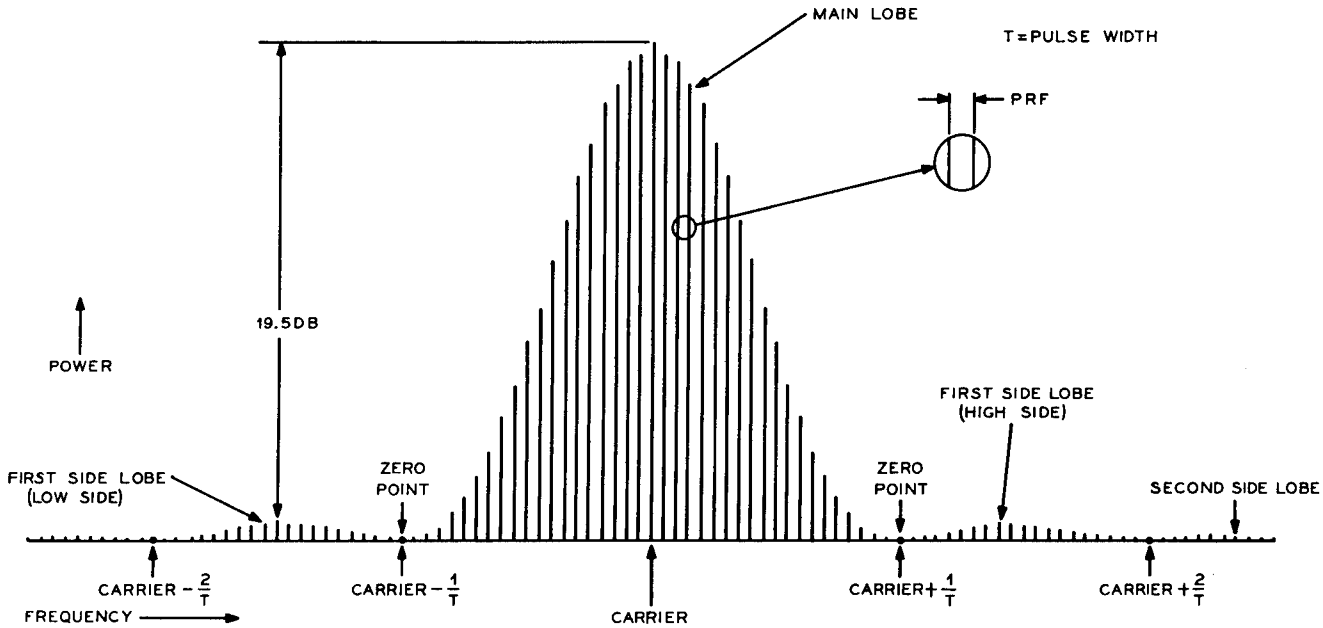


Figure 3-102. Ideal Spectral Display of a Pulse-Modulated R-F Carrier

sociated harmonics; and (2) the other component consisting of the fundamental and odd-harmonic frequencies that comprise the rectangular pulse, as was previously discussed. Figure 3-102 shows an ideal display of that part of the spectrum covered when an r-f carrier is pulse-modulated. The vertical lines in the figure represent the modulation frequencies produced by the PRF and its associated harmonics, while the lobes represent the modulation frequencies produced by the fundamental pulse frequency and its associated harmonics. The vertical lines are separated by a frequency equal to the PRF. The amplitude of the main lobe falls off on either side of the carrier until it is zero at the points corresponding to the second harmonic of the fundamental pulse frequency. The first side lobe is produced by the third harmonic of the fundamental pulse frequency; the second zero point, by the fourth harmonic; and the second side lobe, by the fifth harmonic. In the ideal spectral display, each frequency above the carrier has as its counterpart another frequency equally spaced below the carrier, so that the pattern is symmetrical about the carrier. The amplitude of the side lobes is considered important because, in the ideal spectral display, the first side lobe represents 4.5 percent of the carrier amplitude, and the second side lobe represents 1.6 percent of the carrier amplitude. The main lobe, of course, carries the major portion of the transmitted energy.

(*a*) TRANSMITTER OUTPUT VERSUS RECEIVER RESPONSE.—The importance of the transmitter output characteristics compared with the receiver response becomes readily apparent by inspection of figure 3-103, which shows an optimum receiver response curve superimposed upon an ideal pulse spectral display. The receiver bandwidth is broad enough to include all the energy between the first zero points. It should be noted that the receiver will also respond to the first side lobes, but at reduced level. Any r-f energy that exists outside the limits of the receiver response will, of course, be lost, and the effect will be the same as if the transmitter power were reduced. Since practically all of the transmitted energy is within the limits of the receiver response, as shown in figure 3-103, further broadening of the receiver bandwidth would result in very little increase in energy pickup. It should be apparent, however, that a decrease in bandwidth would cause a definite reduction in energy pickup. The spectrum side lobes contribute very little in terms of pulse amplitude, but are responsible for the straight

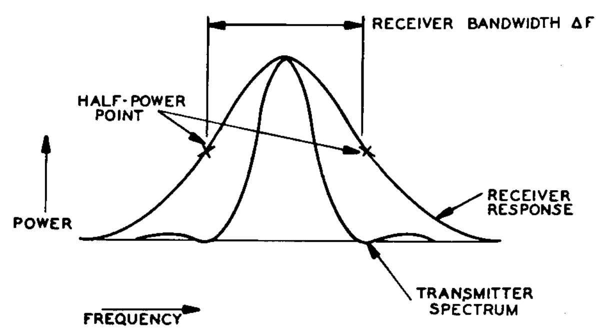


Figure 3-103. Transmitter Spectral Display Compared with Receiver Response Curve

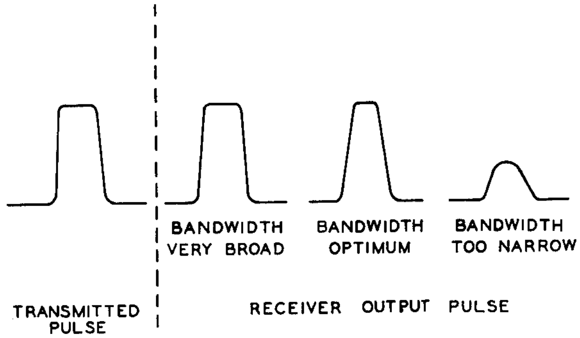


Figure 3-104. Effect of Receiver Bandwidth upon Pulse Shape

edges on the output pulses, as shown in figure 3-104. From this cursory examination, it would seem that an ideal receiver should have sufficient bandwidth to include a great many side lobes, in order to reproduce the transmitted pulse with a high degree of accuracy. However, if the above condition were brought about, the increased bandwidth would allow the receiver to respond to thermal noise which would limit its sensitivity. A reduction of bandwidth, within limits, would not lessen the pulse amplitude, but would reduce noise response. Too great a reduction of bandwidth would result in decreased pulse amplitude, as shown in figure 3-104, due to the loss of some energy in the main lobe. Optimum bandwidth results

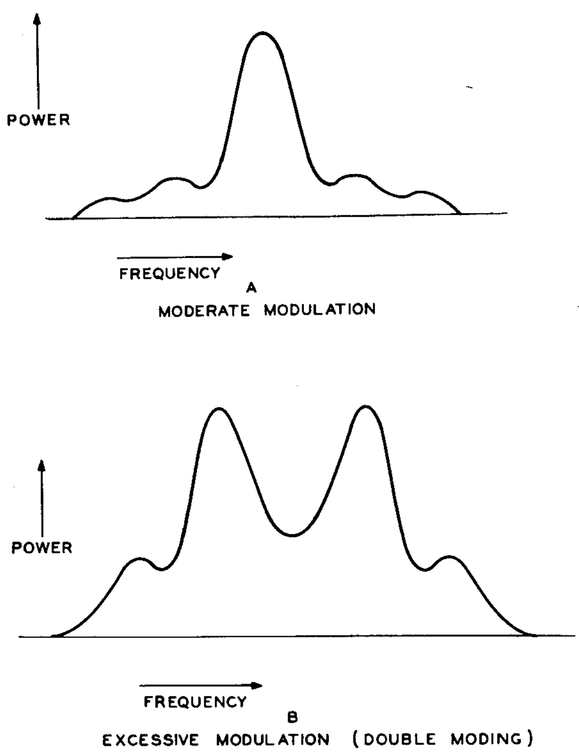


Figure 3-105. Transmitter Spectral Displays, Showing Distortion Resulting from Frequency Modulation

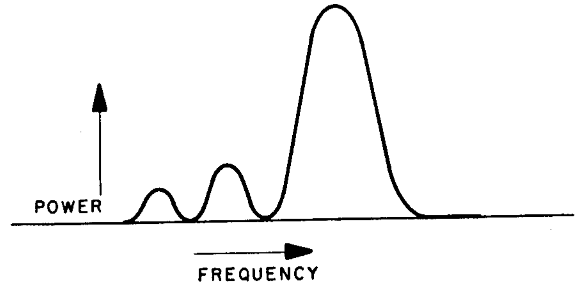


Figure 3-106. Transmitter Spectral Display, Showing Distortion Resulting from Amplitude Modulation

in the greatest receiver sensitivity, but causes a slight distortion of pulse shape. Since accurate pulse shape is important in precision ranging and tracking operations, certain radars designed for this type of service have a receiver bandwidth that is broader than optimum, to provide a sharp leading edge on the pulse.

(*b*) MODULATION DISTORTION.—In a properly functioning radar transmitter, the period of the transmission interval should be as specified, the oscillations during the transmission interval should be of constant frequency and amplitude, and the time required for oscillation to start and stop should be approximately zero. Any deviation from these conditions will produce distortion which is visible on the spectral display in the form of either amplitude modulation or frequency modulation, or both. Figure 3-105 shows the spectral display when FM is present. The zero points are lost, indicating the presence of new frequencies in the spectral display. This has the effect of placing more of the transmitted power in the sidebands, and therefore, results in the loss of energy outside the receiver passband. Part (B) of the same figure shows the spectral display when the amount of frequency modulation is excessive. In part (B), the magnetron is operating at two distinct frequencies (double moding), and the receiver, if tuned throughout its range, would show two tuning points. When the above condition prevails, more than half of the transmitted power is wasted. The presence of amplitude modulation in the transmitted output has the effect of producing dissymmetry in the display, as shown in figure 3-106. The zero points are still clearly defined, but the lobes on one side of the carrier are much larger than normal. In general, distortion resulting from frequency modulation is far more undesirable than distortion from amplitude modulation. Figure 3-107 shows a combination of both types of distortion, which results in a very poor spectral display.

The troubles which give rise to a poor transmitter spectral display are sometimes difficult to locate. Methods used for trouble isolation are discussed in paragraph 3-11.*d.*(5) (*b*)*2*. Briefly, at this point it can be stated that trouble may arise

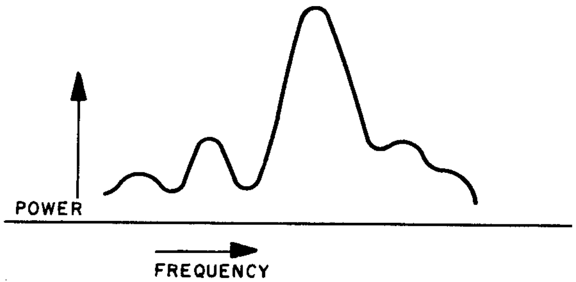


Figure 3-107. Transmitter Spectral Display, Showing Distortion Resulting from Combined Frequency and Amplitude Modulation

from the following causes: (1) Defective magnetron; (2) defective magnet; (3) mismatch in r-f section (pulling); (4) improper pulse shape or amplitude (pushing); and (5) reflections from near-by objects (pulling).

(3) METHODS OF SPECTRUM ANALYSIS.—Two methods of obtaining a graph or display of the spectrum are described in the following paragraphs. The first method requires that a graph of power versus frequency be plotted. It is relatively slow, and demands considerable experience on the part of the technician. The second method is simplified by the use of a spectrum analyzer, which provides, as was mentioned earlier, a display on the screen of a cathode-ray tube corresponding to the graph plotted in the first method. The circuit of a typical spectrum analyzer, of which the TS-148/UP is representative, is discussed briefly. Some spectral displays are examined and interpreted; also a method for frequency measurement is described.

(*a*) METHOD USING FREQUENCY METER.—The use of a frequency meter is a rather simple method of obtaining readings to plot a spectral graph. A high-Q, transmission-type, resonant-cavity meter, such as is found in most echo boxes is utilized, together with a rectifier-meter indicator. The test setup is shown in figure 3-48. Readings are taken at frequent intervals throughout the frequency range of the transmitter, and a graph is made up to indicate meter readings vertically and frequency-meter indications horizontally. If the graph is very carefully plotted, a rough outline of the spectrum is obtained. After the technician has gained experience, he may get a good idea of the spectrum by merely noting how the meter reading varies as the frequency meter is tuned through resonance. All spectral readings must be obtained by rotating the frequency-meter dial in one direction only. If the dial is rocked into position, backlash in the dial drive mechanism will cause an appreciable error. The usual procedure is to approach each reading from the low-frequency side.

(*b*) METHOD USING SPECTRUM ANALYZER.—The spectrum analyzer, which is a form of panoramic receiver, provides a simplified method of analyzing spectral phenomena. A small portion of the transmitter output is coupled into the signal input circuit of the spectrum analyzer. Care must be taken to keep the input low enough to prevent burnout of the attenuator. A directional coupler provides an ideal coupling system, but a pickup antenna may be used. Coupling methods are described in paragraph 3-9.*a*.(3).

1. TEST EQUIPMENT CIRCUIT ANALYSIS.—In the spectrum analyzer, a narrow-band receiver is electrically tuned through a range of frequencies, and the output, in terms of power, is displayed vertically upon an oscilloscope whose horizontal sweep is synchronized with the

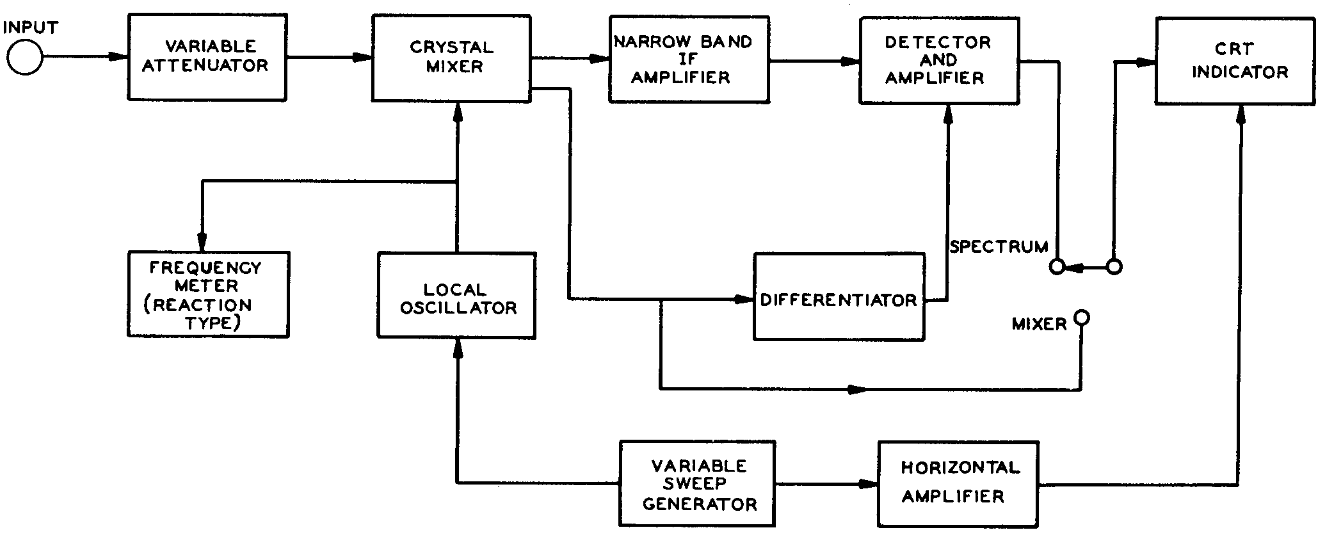


Figure 3-108. Block Diagram of a Typical Spectrum Analyzer

frequency sweep of the receiver. A block diagram of a typical spectrum analyzer is shown in figure 3-108. The receiver employed is of the superheterodyne type. The input, which usually consists of a coaxial-line termination, a broad-band attenuator, and a crystal mixer, is untuned, and, therefore, responds equally well to all signals within the operating band. The local oscillator is usually of the reflex-klystron type, and is made accessible for ease of replacement. The i-f amplifier is a high-gain, narrow-band (50 kc or less) amplifier, usually operated above 20 mc. In some cases, double, or even triple, superheterodyne action is used to obtain the narrow bandwidth required. The i-f section is followed by a detector and amplifier which feed the vertical plates of a cathode-ray tube. The sweep generator produces a variable-frequency sawtooth voltage, which sweeps the local-oscillator repeller (and, therefore, the receiver frequency) and the horizontal deflection plates simultaneously. A reaction-type frequency meter is included, which is designed to absorb local-oscillator power at resonance, thereby indicating the local-oscillator frequency.

On the front panel is a function switch usually labeled MIXER-SPECTRUM. In the SPECTRUM position, the indicator displays the output of the receiver. In the MIXER position, the indicator displays the crystal-mixer current flow, which is a function of the reflex-klystron local-oscillator output. Figure 3-109 shows a typical reflex-klystron chart. It should be noted that the tube will oscillate only at certain voltages, and that, as the voltage is varied, the power output varies. Each separate voltage range of oscillation is called a mode. The modes are relatively flat on top, and each succeeding mode encountered becomes

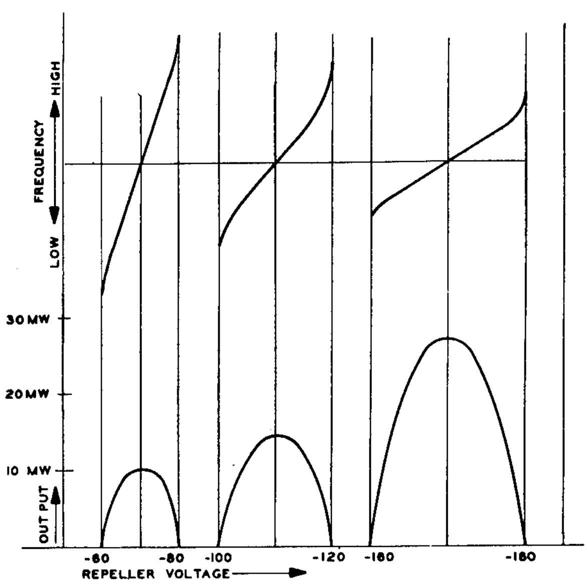


Figure 3-109. ***Typical Reflex-Klystron Chart***

stronger as the repeller is made more negative. Within any given mode, the frequency is proportional to the negative voltage on the repeller, and a frequency range of 60 mc is common in X-band tubes. However, the frequency at the top of each mode is determined by the size of the resonant cavity in the tube; therefore, all of the modes have the same center frequency.

The sweep generator produces a sawtooth voltage which is adjustable in both amplitude and average voltage value. The sawtooth amplitude control, usually called the spectrum width control, has sufficient range to cover at least one mode, and quite often, two. The average voltage control of the sawtooth, usually called the spectrum center control, allows the technician to choose any klystron mode he desires or to use any range within a particular mode. In normal use, only a limited section of one mode is utilized.

It is possible to use the spectrum analyzer as a klystron tube tester. When the function switch is in the MIXER position, the presentation is similar to that shown in figure 3-110, which illustrates one complete klystron mode and a part of another. The pip shown in the center of each mode is the frequency indication caused by the reaction-type frequency meter. The mixer function of the analyzer allows the condition of the local oscillator to be checked; if desired, the oscillator frequency can be set to any specified value. The klystron to be tested may be substituted for the local oscillator in the spectrum analyzer, and the mode pattern observed. The amplitude of the mode indicates power relative to that of the regular oscillator. The tuning range may be examined and any irregularities noted. Each mode should present a smooth regular curve. If desired, the tube under test may be pretuned to an approximate frequency before insertion into the radar, in order to simplify radar tune-up.

2. ANALYSIS OF TRANSMITTER SPECTRAL DISPLAY.—As the spectrum analyzer frequency is swept, the spectral display appears upon the cathode-ray-tube indicator in the form of a series of vertical pulses. These pulses are not to be confused with the vertical lines shown in figure 3-102, which are separated by a frequency equal to the PRF. If the spectrum analyzer has a

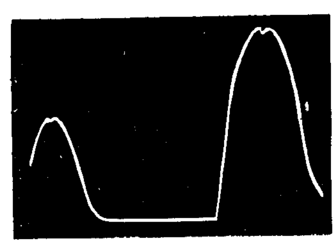


Figure 3-110. ***Klystron Modes—Function Switch in Mixer Position***

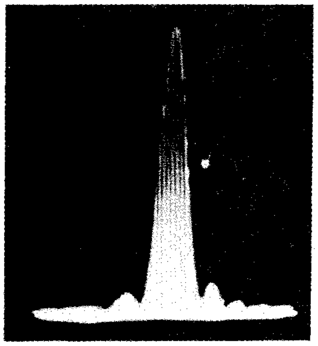


Figure 3-111. Typical Magnetron Spectral Display

bandwidth of 50 kc, a large number of PRF lines are included in each pulse, because the analyzer samples a 50-kc segment of the spectrum each time the transmitter fires. Thus each pulse in the display represents the energy contained in a 50-kc band at the frequency of the analyzer at that instant. If the radar PRF is 200 pulses per second and the analyzer sweep rate is 10 cps, the display will consist of 20 pulses, across the screen of the cathode-ray tube. Figure 3-111 shows a typical magnetron spectral display. These pulses indicate only the general outline of the display, and are much too coarse to reveal the internal structure. Figure 3-112 shows the same conditions with the spectrum width control advanced to produce a greater spread.

3. FREQUENCY MEASUREMENT.—The measurement of frequency is greatly facilitated by the use of a differentiator. Refer to the block diagram shown in figure 3-108. A portion of the crystal-mixer current is applied to a differentiator, and the differentiated waveform is applied to the amplifier section of the spectrum analyzer. Figure 3-113 shows the result of differentiating and amplifying the mixer signal. Part (A) of the figure shows the display with the function switch in the MIXER position, and part (B) is the display with the switch in the SPECTRUM position. Note that the frequency-meter pip now appears as an "S" curve, and that the mode ends are marked by pips. This signal is combined with the spectral

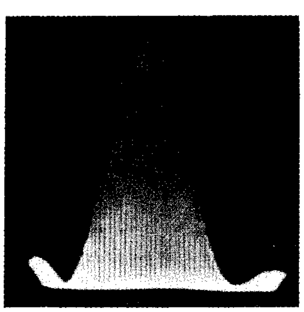


Figure 3-112. Typical Magnetron Spectral Display—Width Control Advanced

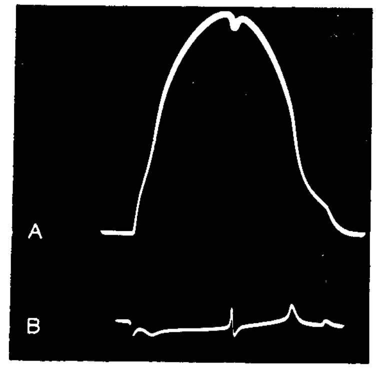


Figure 3-113. Effect of Differentiator upon Mixer Output

display, and appears superimposed on the base line of the pattern, as shown in figure 3-114. The exact frequency is taken at the center of the "S" curve, where it crosses the base line. The pips marking the mode end limits should never be seen on the display, since no spectral indication may be obtained outside the mode limits.

(4) SYSTEM TESTING.—The spectrum analyzer can also be used for some system tests. In this case both the transmitter and local-oscillator signals can be conveniently sampled by means of a small pickup antenna placed near the base of the local-oscillator socket. In this position, the pickup antenna is in the r-f leakage field, and the intensities of the two signals are approximately equal, because of the proximity of the pickup antenna to the weaker source. Because the r-f section of the analyzer is untuned, image signals are also received. Thus, the signal picked up will appear at two points on the analyzer tuning scale. In practice however, an image is just as useful as the real frequency, and is often used in measurements.

Since the analyzer frequency meter is designed to indicate its local-oscillator frequency rather than the input-signal frequency, the most accurate frequency-measurement method is to measure the analyzer local oscillator when the oscillator is tuned above the input signal, and then measure it when the oscillator is tuned below the signal. The signal frequency is then halfway between the two readings.

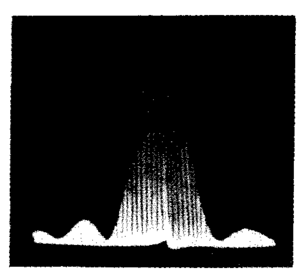


Figure 3-114. Typical Spectral Display, Showing Frequency-Meter Pip

The frequency meter may also be tuned for maximum absorption of the input signal, to obtain a direct indication of the input-signal frequency. Resonance is indicated by a slight reduction in the amplitude of the signal; however, this is difficult to observe.

Figure 3-115 shows an over-all spectral representation of a transmitter and local-oscillator of a particular radar. In this figure, it is assumed that the intermediate frequency of the spectrum analyzer is 25 mc, the radar transmitter frequency is 9375 mc, and the radar local-oscillator frequency is 9405 mc. This produces a radar intermediate frequency of 30 mc. If the spectrum analyzer were capable of showing the entire range of frequencies, the transmitter display would be recorded at 9350 mc and 9400 mc, and the local-oscillator display, which appears as a single frequency, would be recorded at 9380 mc and 9430 mc. (Note: The frequencies shown represent the local-oscillator frequency of the spectrum analyzer and not the signal frequency.) Present (1953) spectrum analyzers, however, cannot show the entire range of frequencies given in figure 3-115. A typical X-band analyzer, for example, is able to present a continuous range of only 50 to 60 mc. To examine various portions of the entire range, the analyzer tuning dial is turned, to vary the range of frequencies being covered. In this way, the entire band, 8500 mc to 9600 mc, may be covered by one instrument.

The spectral range may be made broad enough to display both the radar transmitter and local-oscillator frequencies simultaneously. Because of this feature, the spectrum analyzer is recommended for use in tuning a radar local oscillator to a specified frequency. It is also recommended for use in checking a-f-c action. The procedure for an a-f-c check is as follows: The antenna scanning system is set in motion, and the pulling action on the magnetron is noted. Any lateral motion in the display position indicates a change in frequency, and a moderate amount of shift is to be expected. With the afc in operation, any shift in the radar-transmitter frequency should be accompanied by a corresponding shift in the local-oscillator frequency. Therefore, the distance between the local oscillator and transmitter patterns should remain constant. Excessive pulling is usually evidenced by a distortion of the shape of the transmitter display.

d. OVER-ALL SYSTEM PERFORMANCE.—The testing of radar performance involves a series of measurements which are primarily intended to indicate the ability of the radar to detect targets. The combined results of the tests then indicate the over-all system performance. Two distinct and separate factors are involved in the consideration of radar performance: (1) minimum-range performance; and (2) maximum-range performance.

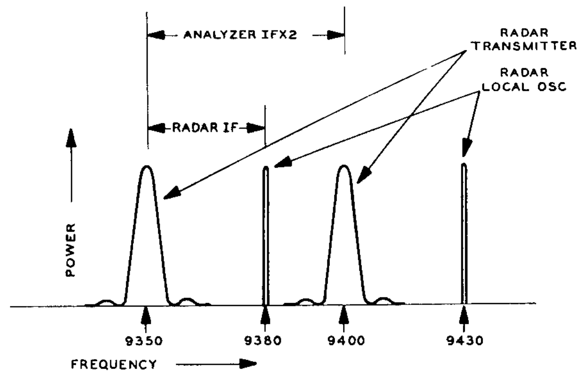


Figure 3-115. Over-All Spectral Representation of Transmitter and Local-Oscillator Output

Both of these factors are discussed in detail in the text to follow.

(1) MINIMUM-RANGE PERFORMANCE.—There are certain radar systems which are designed to detect and range near-by targets. Examples of these are the radar systems utilized for fire control, aircraft interception, aircraft altitude indicators, and ground-controlled-approach systems. The TR recovery time and transmitter pulse width are important factors in determining the effective minimum range.

(*a*) TR RECOVERY TIME.—If a target has a range of 200 yards, the echo is returned to the radar in about $1\frac{1}{4}$ microseconds after the occurrence of the transmitter pulse. If the receiver is to respond to this echo, the TR switch must recover sufficiently during this short interval to allow passage of energy to the receiver. Since a near-by target returns a strong signal, the recovery need not be complete, because the receiver will respond to a strong signal, even at reduced sensitivity.

(*b*) TRANSMITTER PULSE WIDTH.—As mentioned above, minimum-range performance is also influenced by the transmitter pulse width. Long-range search radars may use a pulse width of 2 microseconds or over, which represents a free-space range of over 320 yards. Radars designed for close-range work have pulse widths as short as $\frac{1}{4}$ microsecond, which represents only a little over 40 yards of free-space range. Furthermore, high-power radars may require the use of a pre-TR tube, to prevent transfer of harmonic energy through the TR; as a result, the recovery period may correspond to 2000 yards of range or more.

(2) MAXIMUM-RANGE PERFORMANCE.—The factors which determine the maximum range of a radar system are rather diverse; however for the purpose of the discussion to follow, they may be divided into two general categories. The first category, which is not controllable by the

maintenance activity, consists of target reflection and propagation factors. The second category is made up of system performance factors, which are controllable to some degree by the maintenance activity.

(*a*) TARGET REFLECTION. — Four principal factors enter into the determination of the amount of energy reflected by a radar target: (1) The material of which the target is constructed; (2) the surface area presented to radar; (3) the configuration of the surface presented to radar; and (4) the operating frequency of the radar. In general, it may be said that the amount of energy reflected from a target is a very complex consideration, and that the reflected-signal energy cannot be predicted with any degree of accuracy. Therefore, when information on the reflected-signal strength is required, it is found by direct measurement. For different target configurations, the reflected-signal strength varies considerably.

(*b*) PROPAGATION FACTORS—Atmospheric conditions play a very important part in radar performance. Some of the more common factors are: (1) Duct formation; (2) temperature inversion and atmospheric refraction; (3) rain echoes and scattering; and (4) atmospheric absorption.

1. DUCT FORMATION.—Duct formation occurs when there is a sharp discontinuity in the atmospheric conditions close to the ground. The discontinuity reflects a transmitted signal in about the same manner as a metallic surface, and thus directs the wave back to earth, where reflection occurs again. Therefore, the space between the earth and the discontinuity, in effect, acts as a waveguide, and, as a result, an abnormally long radar range may be observed.

2. ATMOSPHERIC REFRACTION.—Atmospheric refraction is a phenomenon by which radar waves are bent in the earth's atmosphere. Under normal conditions the atmosphere is more dense at the surface of the earth and less dense as the altitude increases. As a result, electromagnetic energy travels slower at lower altitudes, and is effectively bent downward. The radar horizon is therefore extended about 15 percent beyond the calculated horizon under normal conditions. This phenomenon may be further augmented by a condition known as temperature inversion, which is caused by a warm air mass surmounting a colder air mass. The increased temperature at higher altitudes further decreases normal atmospheric density, as compared to the surface density, and the radar horizon is greatly extended. Temperature inversion is very common where warm air masses from land move over the cool air directly over a large body of water. The opposite condition can also prevail if the gradation of density is reversed, in that a colder air mass surmounts a warm air mass; refraction will then cause the radar wave to bend upward and thus greatly reduce the radar horizon.

3. RAIN ECHOES AND SCATTERING.—Moisture in the atmosphere may cause microwave signals to be either scattered or reflected, depending upon the size of the droplets. If the droplets are rather large, as in a heavy rain cloud, reflection occurs and causes an echo. This effect is very noticeable at the higher microwave frequencies. Smaller droplets may cause scattering rather than reflection, causing the range to be greatly reduced.

4. ATMOSPHERIC ABSORPTION.—It has been recently discovered that atmospheric gases have the property of absorbing certain microwave frequencies. Each gas has its own absorption spectrum, and, of the gases studied thus far, each is unique in regard to the absorption frequencies. For example, water vapor absorbs strongly above 10,000 mc, showing a peak at approximately 23,000 mc. Oxygen absorbs very strongly at about 60,000 mc, and ammonia gas at about 24,000 mc. The fact that the absorption characteristics of various gases differ markedly has made it possible to analyze gases by means of their absorption spectra. The absorption effect is very undesirable in radar operations, because it results in reduced range at the frequencies of maximum absorption. Fortunately, this effect is not pronounced in the X band and at lower frequencies, but it does make K-band equipment very unreliable.

(*c*) RADAR PERFORMANCE FACTOR. —Since radar system performance depends upon the condition of the radar, it remains as the only factor which may be controlled to some degree by maintenance, and, therefore is the most important. Radar performance is dependent upon such items as: (1) transmitter power, (2) transmitter frequency, (3) transmitter spectrum, (4) receiver bandwidth, (5) receiver sensitivity (MDS), (6) T-R recovery, and (7) a-f-c operation.

1. SYSTEM SENSITIVITY. — System sensitivity is the ratio of the transmitted power admitted by the receiver pass band to the MDS power. A precise determination of system sensitivity, therefore, involves a check of both the transmitter spectral display and the receiver pass band. It follows that if half the transmitted energy is outside of the receiver pass band, the power is effectively cut in half.

System sensitivity is proportional to maximum range, as shown in the following expression: Range (maximum) $=\sqrt[4]{P_t/P_{mds}}$, where P_t is the transmitter peak power encompassed by the receiver pass band, and P_{mds} is the minimum discernible signal power. It should be noted that, in the above expression the fourth root is taken rather

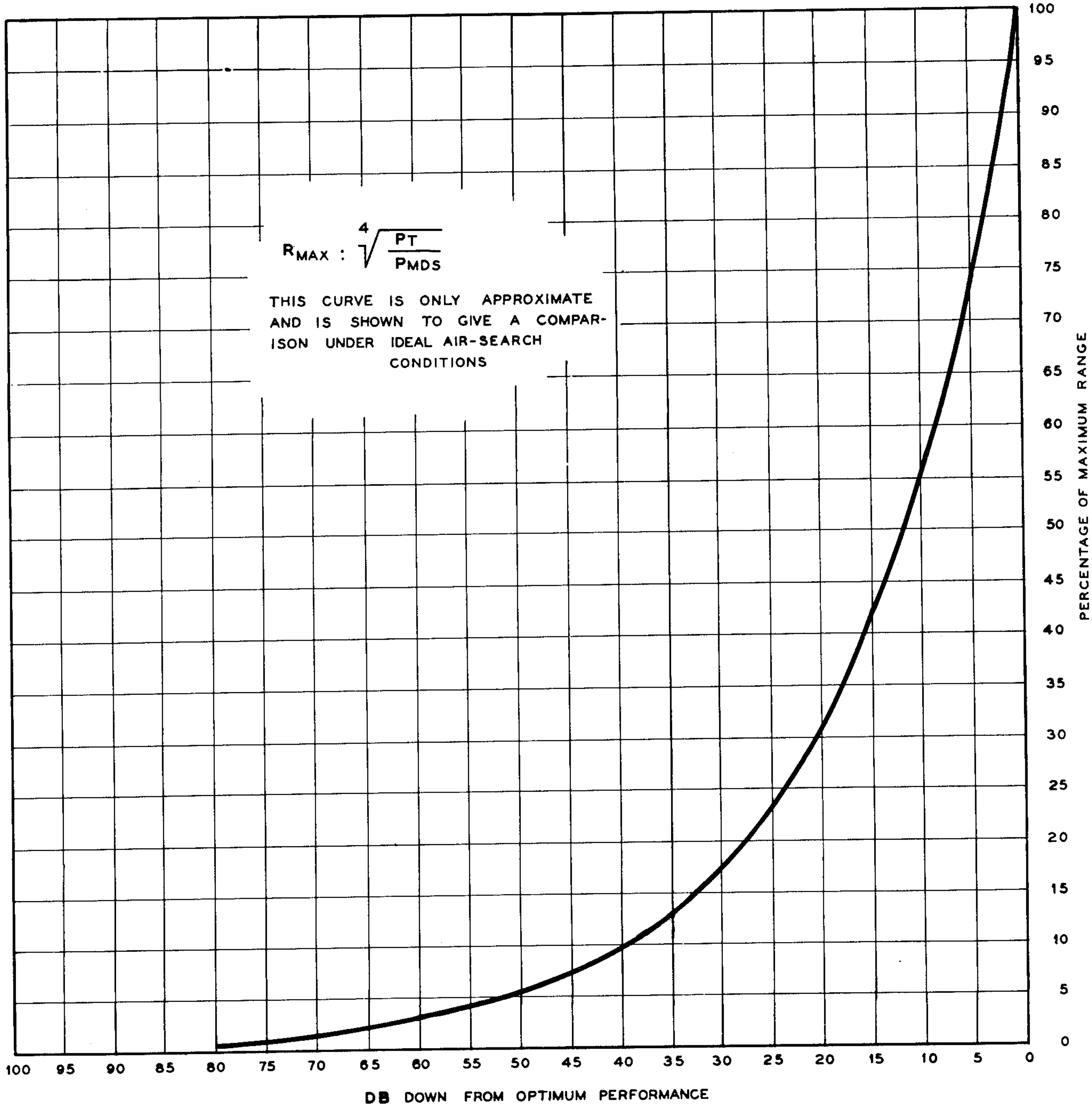


Figure 3-116. System Performance vs Maximum Range

than the square root. This is explained by the fact that the inverse square law, which is used to determine the strength of a transmitted signal over a given distance, is applied twice, once for the forward travel and once for the echo return.

When the transmitted power and the MDS power are measured in units of watts, the sensitivity of the radar system is calculated in terms of a power ratio by simple division. However, these two power figures are usually measured in dbm, and the system sensitivity is more conveniently calculated as follows: System sensitivity (db) = P_t (dbm) — P_{mds} (dbm). (Note: The MDS figure is a negative dbm quantity, and, as such, must be subtracted algebraically from the transmitted power.)

The sensitivity of a radar system is specified in the instructional literature accompanying the equipment. Any loss of sensitivity results in a corresponding decrease in the maximum range covered by the radar. Figure 3-116 shows graphically how a decrease in system sensitivity, given in db below optimum performance, causes a decrease in the maximum range, given in percentage loss.

Inspection of the figure reveals that, for the first five db decrease from optimum, there is a range loss of about 5 percent per db. At a point corresponding to about a 12-db loss, the resultant loss in range is 50 percent of maximum. (In addition, a loss of receiver sensitivity is just as important as a loss of transmitter power.) In the case of a search radar, if the range is 50 percent of maximum, the search area is only 25 percent of maximum. The above condition represents very poor performance.

(3) RESONANCE CHAMBER, OR ECHO BOX.—An echo box, or resonance chamber, consists basically of a resonant cavity, the dimensions of which are determined by the frequency band in which operation takes place. The resonant cavity is tuned by a plunger, which can be adjusted back and forth in the cavity. This plunger is mechanically connected to a calibrated tuning dial. Connection to the radar set is made by a pickup dipole or a coaxial horn placed in the antenna radiation field, or by means of a cable which is connected to a directional coupler in the transmission line of the radar. An output power meter circuit made up of a microammeter, a crystal, a filter capacitor, and an attenuator (to prevent overloading) are usually included as a part of the echo box test equipment. The output meter indicates the relative power output of the radar transmitter. Refer to the block diagram of an echo box, figure 3-117.

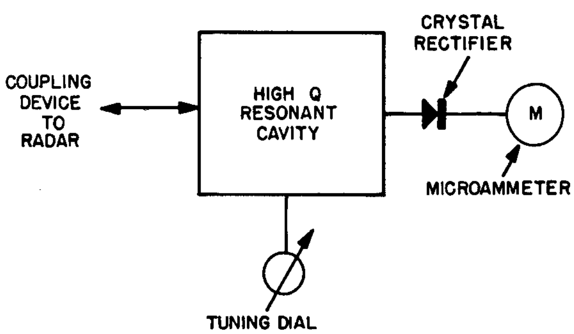


Figure 3-117. Block Diagram of Typical Echo Box

(*a*) THEORY OF OPERATION. — Any tuned circuit may be shock-excited by the sudden application of energy. When the excitation is removed, the tuned circuit will continue to oscillate (ring) for a length of time. The greater the Q of the resonant circuit, the longer the ringtime. The echo box picks up r-f energy from a transmitter pulse. When the cavity is tuned to the frequency of the pulse, the r-f energy picked up causes oscillations to build up in the resonant cavity. Refer to figures 3-118 and 3-120. These oscillations continue after the radar pulse is cut off; however, the amplitude of each succeeding oscillation decreases, because of internal losses and output-meter dissipation, and because some of the energy is coupled back to the radar set. The energy coupled back is detected by the receiver, and appears as a pattern on the radar indicator. See figure 3-119. Ringtime

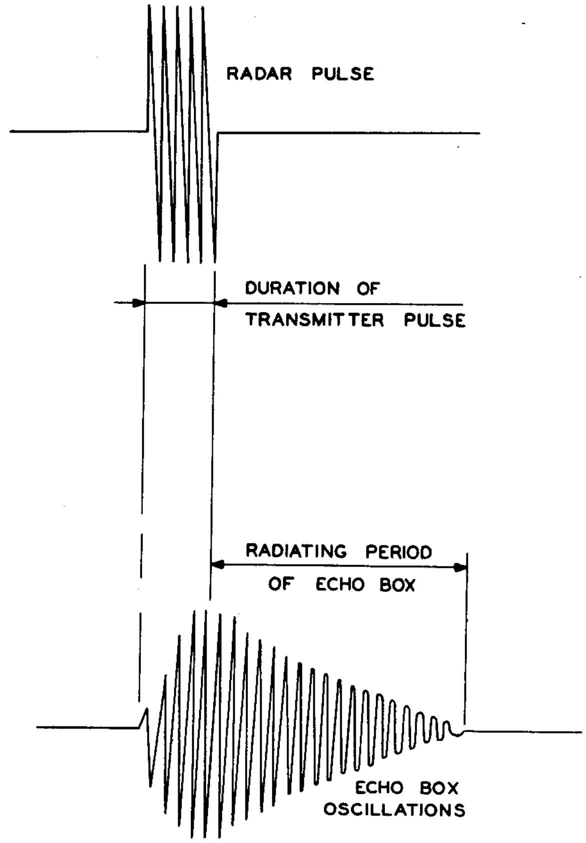


Figure 3-118. Relationship Between Transmitter Pulse and Echo-Box Ringing

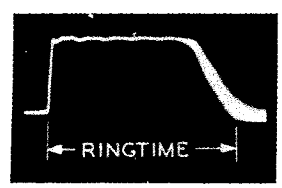


Figure 3-119. Ringtime Indication on A Scope

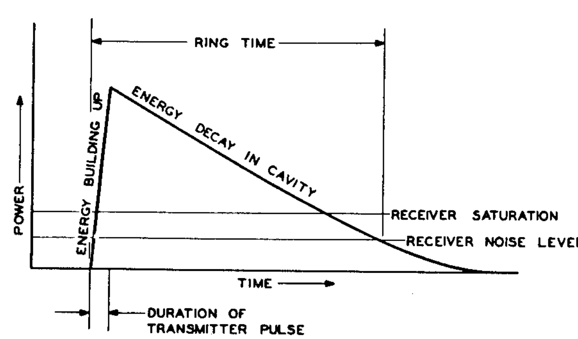


Figure 3-120. Energy Rise and Decay During Ringtime

is measured in terms of either yards or microseconds between the start of the transmitter pulse and the point where the ringing signal reaches the noise level of the radar receiver. The value of ringtime is influenced by the following factors: (1) receiver sensitivity; (2) peak transmitter power; (3) coupling loss between echo box and radar; (4) transmitter pulse width; and (5) the Q of the echo box. It should be noted that the first two factors provide a check of system sensitivity. This check, however, is not reliable unless the other three factors are either known or kept constant.

(*b*) COROLLARY DATA.—Because of its simplicity and compactness, the echo box is a very valuable test equipment for periodic system testing.

It must be constantly kept in mind that an echo box presents relative information. The echo-box installation must first be calibrated with standard test equipment before the information has any practical value. In fact, the echo box must be recalibrated at regular intervals, to ensure that the information gained is reliable.

The installation of an echo box is very important. If the radar has a directional coupler, the echo box is located at some convenient point, and an r-f cable is used to connect the echo to the coupler. It is important that the same cable and echo box be used for all subsequent testing.

If the radar has no directional coupler, a pickup antenna is permanently installed at a point where reflections are at a minimum, and the echo box is connected to the pickup antenna with a r-f cable. Again it is important that the same pickup antenna, cable, and echo box be used for any subsequent measurements.

(*c*) CALIBRATION.—It is possible to calibrate the echo box so that ringtime may be correlated with system sensitivity; future ringtime readings can then be converted into sensitivity readings. The conversion is easily made, because the change in ringtime per db change in sensitivity is specified for an individual echo box. A common figure encountered in the field is about 100 yards per db. Thus, if a radar has lost 1000 yards of ringtime, the sensitivity has decreased about 10 db. When the ringtime is found to be low, the meter reading is noted, and then compared to the calibrated reading. Since the meter measures relative transmitter output, a low reading indicates trouble in the transmitter. A normal meter reading, coupled with a low ringtime indication, however, points to trouble in the radar receiver.

To calibrate an echo-box installation, proceed as follows:

1. Orient both the radar and pickup antennas for maximum pickup. Unless reflections are found to be present, this step represents the final adjustment of the pickup antenna.

2. Record all settings of radar controls that affect PRF and pulse width.

3. Adjust radar receiver gain for about ¼-inch of noise on A scope. If an A scope is not used, connect a synchroscope to the receiver output.

4. Tune echo box for greatest ringtime indication on A scope.

5. Adjust coupling in echo box to give a standard meter reading—75 percent of full scale.

6. Carefully read ringtime; at the same time note the echo-box temperature.

7. Measure system sensitivity, using standard test equipment and procedure. Refer to paragraph 3-11.*a*.(2) (*c*). Ringtime is then correlated with system sensitivity, as previously explained, so that future ringtime readings can be converted to sensitivity readings.

(*d*) SYSTEM SENSITIVITY TEST.—A calibrated echo box may be used to measure system sensitivity by following the steps given below:

1. Orient radar and pickup antennas.

2. Set up radar controls to correspond to the settings recorded during calibration (step *2*).

3. Adjust receiver gain for ¼-inch noise on A scope.

4. Tune echo box for greatest ringtime indication. Note: Maximum meter reading should occur at the same point.

5. Read meter and ringtime. Compare these readings with the previous figures obtained, and convert any change in ringtime reading to the db change of system sensitivity.

6. Note the temperature of the echo box. If the temperature differs from that recorded during calibration, a correction factor specified in the maintenance literature must be applied to the ringtime reading. Note: At a temperature lower than the calibration temperature, the resistance of the metal of the echo box decreases; hence, the echo box has a higher operating Q and, therefore a greater ringtime.

(*e*) CHECKING TR RECOVERY TIME.—TR recovery time may be checked by the use of an echo box, as follows:

1. Note the slope of the response between receiver saturation and noise level.

2. Detune echo box until this slope just starts to change.

3. Read ringtime. This reading is the TR recovery time.

(*f*) SPECTRUM ANALYSIS.—The spectrum of a transmitter may be analyzed by the use of an echo box, as follows:

1. Detune echo box by rotating tuning dial in one direction until meter indicates zero.

2. Rotate tuning dial in the opposite direction, and record the meter readings at various dial positions.

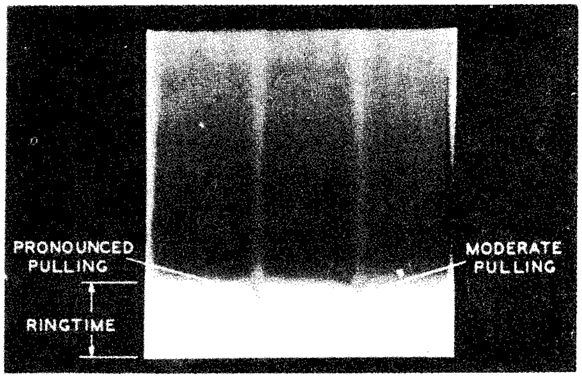


Figure 3-121. Ringtime Indication on B Scope, Showing Effect of Magnetron Pulling

3. Plot a graph of meter readings (vertical) and dial readings. The graph then represents the transmitter spectrum.

(*g*) CHECKING MAGNETRON OPERATION.—A good means of observing magnetron pulling during scanning is available, if the echo box is coupled to the radar by means of a directional coupler. With the antenna pointing at free space, tune the echo box for maximum ringtime. Start the antenna scanning, and observe the presentation on the PPI or B scope. On a PPI scope, normal magnetron operation produces a smooth, unbroken circle of light; on a B scope, the pattern is a smooth, unbroken bar of light. Magnetron pulling is evidenced by any irregularity or breakup in the edge of the scope indication. Refer to figure 3-121. The azimuth at which pulling occurs may easily be read from the indicator. If desired, the antenna scanning may be stopped at the pulling point, and the degree of pulling measured.

(*h*) TESTING SUMMARY. — The tests described in parts (*c*), (*d*), (*e*), (*f*), and (*g*) of paragraph 3-11.*d.*(3) should be performed at periodic intervals, as specified in the maintenance literature for the radar system, and the results tabulated in the specified charts or forms, so that any change in performance may be easily observed and corrected. The periodic echo-box test results should also be checked at regular intervals against test results obtained with the equipment used in the original calibration.

(*i*) PRECAUTIONS.—The following precautions should be observed when using an echo box:

1. The same echo box, cables, and pickup device should be used each time the tests are performed.

2. Make certain that the same radar test conditions are established each time the echo box is used. Record all control settings.

3. Measure ringtime very carefully. It is good practice to take several readings and average the results. Use a precision range marker if possible.

4. Keep accurate records, as specified in the maintenance literature for the radar system.

5. Detune or disconnect the echo box when it is not in use.

(4) MULTIRESONANT ECHO BOX — GENERAL.—The multi-resonant type of echo box, which is used to some extent in the field, is made up of a cavity of irregular shape, and of a size corresponding to several wavelengths. Because of its construction, the multiresonant echo box effectively functions as many cavities of different sizes with overlapping response curves. Consequently, it is resonant over a broad band of frequencies, and does not require tuning. In most cases a pickup antenna is built into one end of the box. The multiresonant echo box has an extremely high value of Q. However, because frequency and size are interdependent, only those frequencies of the X band or higher permit construction of reasonably sized boxes.

(5) SYSTEM PERFORMANCE — TROUBLE SHOOTING.—A radar system may show a gradual decline in performance and eventually reach a point where corrective maintenance is required. On the other hand, the system may suddenly develop a fault. The suddenly developed fault is immediately obvious. However, in the periodic testing and recording of performance, the purpose is to anticipate possible troubles. Periodic testing shows any trend as it develops, and in many cases minor corrective action at this time will prevent a future major breakdown.

Under the title of RADAR TESTING, system performance testing has been discussed, and also, various testing procedures which aid in localizing trouble have been covered. One of the most difficult jobs the technician meets is locating the specific cause of a certain trouble. In localizing the cause of a loss of performance, the first step is to determine whether the trouble is located in a particular unit, such as the modulator-transmitter or the receiver. This may be done by the use of the echo box and the information listed in figure 3-122, or by the use of the various test equipments and procedures described in previous paragraphs of RADAR TESTING. From there the specific circuits or source of power for that unit are tested. In the following text, both receiver and transmitter troubles are analyzed in detail (the power-supply trouble, being rather straightforward, are not covered).

(*a*) RECEIVER TROUBLES.—Poor system performance may be caused by low receiver sensitivity (high MDS), poor a-f-c operation, and poor minimum range.

1. LOW RECEIVER SENSITIVITY.—Low receiver sensitivity is evidenced by a high

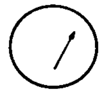
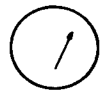
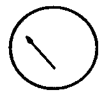
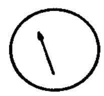
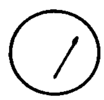
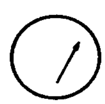
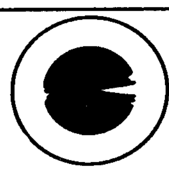
EFFECT	APPEARANCE ON		PROBABLE CAUSE
	RADAR INDICATOR	ECHO BOX METER	
RINGTIME AND TEST SET OUTPUT SATISFACTORY			RADAR PERFORMANCE SATISFACTORY
RINGTIME LOW, OUTPUT READING SATISFACTORY.			RECEIVER TROUBLE: DETUNED MIXER OR LOCAL OSCILLATOR, BAD CRYSTAL, EXCESSIVE I-F NOISE, ADJUSTMENT OF PROBES IN MIXER CAVITY. DETUNED T-R BOX.
RINGTIME LOW, TEST SET OUTPUT VERY LOW.			LOW POWER OUTPUT. CHECK SPECTRUM.
RINGTIME LOW, TEST SET METER READING LOW.			TROUBLE PROBABLY IN TRANSMITTER AND RECEIVER AND/OR TROUBLE IN TRANSMISSION LINE.
RINGTIME ERRATIC, TEST SET METER READING STEADY.			TEST SET DETUNED. BAD PULSING, DOUBLE MODING TRANSMITTER, OR LOCAL OSCILLATOR POWER SUPPLY TROUBLE. CHECK SPECTRUM.
RINGTIME ERRATIC, TEST SET OUTPUT READING ERRATIC.			FAULTY TRANSMISSION LINE OR CONNECTION — CONDITION WORSE WHEN LINE IS RAPPED
END OF RINGTIME SLOPES GRADUALLY, PERHAPS EVEN EXCESSIVE RINGING. GRASS APPEARS COURSE. TEST SET OUTPUT READING STEADY AND SATISFACTORY.			OSCILLATING I-F AND/OR NARROW BAND RECEIVER.
PRONOUNCED DIP IN RINGTIME AT END OF PULSE.			FAULTY TR OR DUE TO RECEIVER GATING ACTION
RINGTIME VERY SLIGHTLY LOW, POOR OR BAD SPECTRUM.		 POOR SPECTRUM	TRANSMITTER TROUBLE.
BLANK SPACES OR ROUGH PATTERN ON PPI RINGTIME INDICATOR, TEST SET OUTPUT READING VARIES AS RADAR ANTENNA IS ROTATED.			FREQUENCY PULLING OF TRANSMITTER DUE TO BAD ROTATING JOINT OR TO REFLECTING OBJECT NEAR RADAR ANTENNA.

Figure 3-122. Echo Box Trouble Indications

MDS test figure. The reasons for this condition may be either excessive noise generation or excessive signal loss preceding the i-f amplifier section. As long as the noise present in the receiver output is excessive, the i-f amplifier cannot contribute to the sensitivity. When defective or improperly adjusted, the following items may cause low receiver sensitivity: crystal mixer, local oscillator, i-f amplifier (first two i-f stages), and the TR and ATR tubes.

Crystals may be tested most effectively under actual operating conditions. However, a series of crystal testers, of which the TS-268/U is representative, is available, and one of these testers may be used to correlate the d-c characteristics with circuit performance. Important crystal characteristics are conversion loss, noise figure, i-f impedance, and r-f impedance. These characteristics may be correlated with front-to-back resistance ratio and back current at 1 volt.

2. POOR A-F-C OPERATION. — Because proper operation of the a-f-c circuit is primarily dependent upon coupling between the a-f-c crystal mixer, the local oscillator, and the output of the magnetron, this portion of the circuit should be checked first. A variable coupling is usually provided to adjust the amount of local-oscillator signal injection to the a-f-c crystal mixer. Care should be taken to prevent overloading of the a-f-c crystal mixer, and reference should be made to the applicable instruction book as to the correct crystal current for proper operation. Usually one milliampere of crystal current is the allowable limit. If the degree of coupling is found to be correct, the trouble may lie in a defective local-oscillator tube. The local oscillator must operate smoothly over the desired pull-in frequency range if normal a-f-c operation is to take place. In addition, it is essential to make sure that the local oscillator is operating in the correct mode. A magnetron with an improper frequency spectrum may also cause the a-f-c circuit to seem defective.

3. POOR MINIMUM-RANGE PERFORMANCE.—Minimum-range performance is controlled by the recovery time of the TR tube (and, if used, the pre-TR tube). Excessively long recovery time, of course, indicates the end of the useful life of a TR tube.

(*b*) TRANSMITTER TROUBLES.—The major troubles or indications of trouble met with in radar transmitters are incorrect operating frequency, poor spectrum, and low output. As a further complication, the troubles may occur intermittently.

1. INCORRECT OPERATING FREQUENCY.—The trouble of incorrect operating frequency usually breaks down into two possible causes: (1) The magnetron may be defective; or (2) pulling may exist because of some fault in the r-f system or from strong reflections from a nearby object.

When a new magnetron is inserted to correct off-frequency operation, it is not necessarily true that the original magnetron is defective. Individual constructional differences of magnetrons may vary, causing one to be pulled more easily by external conditions than another of the same type number. It is seen, then, that irresponsible replacement of apparently defective magnetrons may result in the rejection of good tubes. It is first necessary to check for the presence of pulling, to determine whether the magnetron actually is at fault. This check is made by measuring the VSWR of the r-f system, with the slotted line placed as close to the magnetron as possible, or by feeding the magnetron output into a dummy r-f load and rechecking the frequency. When off-frequency operation occurs with a low VSWR, the indication is that the magnetron should be replaced, unless, of course, it is of the tunable type.

2. POOR SPECTRUM.—As was previously discussed, spectrum analysis is of considerable importance in the maintenance of radar systems. The reason for a poor magnetron spectral display or graph may be: (1) magnetron pulling, (2) magnetron pushing, (3) defective magnet, or (4) defective magnetron.

3. MAGNETRON PULLING.—The test for magnetron pulling may be made by means of VSWR measurements or by the use of a dummy antenna, as mentioned above. Magnetron pulling may cause frequency shift, but this may go unnoticed if the frequency is still within the operating band.

4. MAGNETRON PUSHING.—A poor spectral display or graph is frequently evidence of magnetron pushing, and this fault is the result of improper modulator operation. When the output pulse is of improper shape or amplitude, especially at lower power levels, excessive AM or FM may be present. The test applied to the modulator is made with the aid of a synchroscope and voltage divider. The voltage divider serves the purpose of reducing the modulator pulse to a usable amplitude. This amplitude is observed and multiplied by the appropriate factor. The pulse shape is observed and compared with available waveform charts. Under certain conditions, the magnetron may cause improper loading of the modulator, and thus introduce pulse distortion. The use of a dummy load for the modulator eliminates this condition. The modulator dummy load is a resistive impedance equal to the firing impedance of the magnetron; in most cases, a voltage divider is built into the test equipment to facilitate the measurement of pulse amplitude. This load replaces the magnetron during pulse measurements, and, therefore, helps to isolate trouble definitely to the modulator.

5. DEFECTIVE MAGNET. — A poor spectral display or graph often indicates defects in the magnetron magnet. Low magnetic strength may result from careless handling. Improper mounting may cause the magnetic field to enter the magnetron at the wrong angle. Mounting difficulties are quickly found on inspection, and magnetic field strength may be checked by using a gaussmeter. Under some conditions, reversal of the magnet may improve the spectrum.

6. DEFECTIVE MAGNETRON. — A poor spectral display or graph may indicate a defective magnetron. A weak magnet may cause the magnetron input to exceed rated values; if so, continued operation will result in a damaged unit. Missing lines in the spectral display are the result of magnetron arcing, and, if excessive, may completely destroy the shape of the spectrum. New magnetrons display moderate arcing until seasoning is completed, and, therefore, should be allowed a sufficient breaking-in period before the spectrum is analyzed. As mentioned previously, the end of the useful life of a magnetron is characterized by an increase in arcing and general instability. When the output power is low, it usually indicates a weak magnetron or a low modulator output. This uncertain condition may be resolved by testing the modulator output pulse; normal pulse indicates that the trouble is in the magnetron.

(*c*) MTI TROUBLES. — Moving-target-indicator circuits are susceptible to the troubles commonly encountered in other electronic circuits. Since the delay line and the coherent oscillator are common only to the MTI circuit, these will be discussed briefly.

1. EXCESSIVE DELAY LINE ATTENUATION.—Excessive delay line attenuation may be caused by dirty mercury. The mercury should be drained and then replaced with clean mercury. For detailed instructions, refer to the applicable instruction book. When a delay line is refilled with mercury, or if it has been subjected to severe vibration, excessive attenuation may result. Allowing the delay line to rest for approximately 24 hours will result in the mercury settling and the condition will be corrected.

2. TOTAL FAILURE OF DELAY LINE.—Total failure of the delay line is usually caused by either broken crystals or by a shorted coaxial cable connector in one of the two transducers. A broken crystal will be apparent by leakage of mercury at the transducer tank. If no leakage is present, it may be assumed that the trouble is in the coaxial connectors. If a crystal must be replaced, refer to the applicable instruction book for detailed instructions.

3. COHERENT OSCILLATOR. — The coherent oscillator has been designed to be exceptionally stable. The usual frequency tolerance of the MTI circuits requires not more than a 10-cycle deviation in frequency during the interval between transmitted pulses. Because of this extremely small tolerance, the tuning of the coherent oscillator should be checked carefully and if necessary, readjusted. Since different types of MTI equipments are so much different, no attempt will be made to describe any special procedure. For complete detailed instructions, refer to the applicable instruction book.

3-12. SONAR TESTING—GENERAL.

a. INTRODUCTION TO SONAR TYPES.—Many similarities exist between sonar and radar equipments, and therefore the testing techniques and practices are closely related. The major differences between sonar and radar equipment are in the method and medium of information propagation. In sonar the method, transducer, and the medium, water, necessitate the use of lower ranges (sonic and supersonic) of operational frequencies than those used for radar. The problems peculiar to sonar equipment, which have been introduced by these three factors will be discussed in more detail, following a brief discussion of the basic types of sonar equipment and of basic sonar fundamentals.

(1) ECHO-RANGING SONAR.—The function of echo-ranging equipments is to determine the range and bearing of objects in the water. The equipment transmits a supersonic signal horizontally into the water, and if this signal impinges on an object of sufficient size and proper composition, an echo is returned to the equipment, where it is received and presented to the operator either audibly or visually. Echo-ranging equipments are divided into three classifications, according to their method of operation. These types are: (1) searchlight, (2) scanning, and (3) continuous wave (cw).

(*a*) SEARCHLIGHT TYPE.—For searchlight operation, energy is transmitted at only one bearing, and the transducer is held at that bearing to listen for a returned echo. The equipment is allowed to ping and listen a few times at one bearing, and then the transducer is advanced a few degrees in bearing and the process of ping and listen is repeated. The advantage of this type of operation is that all of the power output is focused into a concentrated beam, and therefore greater ranges are available. The disadvantages are: a target can be passed over without detection unless the operator is accustomed to the equipment; a target might approach from opposite the bearing being searched without being observed until such time as the searchlighting procedure would allow the transducer to approach the bearing of the target; and the maintenance of an appearing and disappearing target requires a higher degree of proficiency on the part of the operator.

(*b*) SCANNING TYPE.—When the sonar equipment is of the scanning type, a pulse of supersonic energy is transmitted in all directions into the water, and then there is a scanning in azimuth for all echoes, which are made to appear as bright spots at the correct bearing on the screen of a cathode-ray tube. Simultaneously, an echo signal is fed to the audio channel from the audio scan switch, which can be directed to any desired azimuth for aural reception of the characteristics of the echo signal. The advantages of this type of operation are that all bearing sectors can be visually covered simultaneously, along with audio coverage at any desired bearing, and that a less-experienced operator is capable of operating this type of equipment. The disadvantage is that the transmitted energy must be radiated in all directions instead of in a concentrated beam, and therefore the maximum available range is greatly reduced in comparison with searchlight operation.

(*c*) CONTINUOUS-WAVE (CW) TYPE.—The continuous-wave type of echo-ranging equipment differs from the searchlight and scanning types described above principally in that (1) transmission is continuous (except for a short blanking period) and not pulsed as are the other two types, and (2) the projector or transducer rotates continuously. The echo of the continuous transmission is returned and compared for a change in frequency in the receiving circuits of the equipment. From the difference between the transmitted frequency and the target echo return, the range and bearing of various targets is determined. This information is usually presented on a cathode-ray-tube indicator. Aural indication is also provided to identify targets. An advantage of this type sonar is that a nearly continuous plan-position indication (PPI) of all underwater objects within sonic range is provided, and also that relative target motion can be observed on the indicator. A disadvantage of this type sonar is that the operator must be quite well experienced to interpret the various sounds produced for aural recognition.

The c-w type of sonar is described above because it is an echo-ranging type. However, since this type of sonar is seldom encountered, and, since most of the measurements are performed with test equipment supplied with the c-w equipment, reference to the applicable instruction book for the particular equipment should be made by the technician for detailed testing and other maintenance procedures.

(2) TARGET DEPTH DETERMINING EQUIPMENT.—The basic purpose of this type of equipment is to provide a means of determining the depth of an underwater object. Depth-determining equipments are normally used in conjunction with an echo-ranging equipment, a recorder-resolver equipment, and sonar computer equipment, to form a complete, integrated sonar system. Depth-determining equipments are divided into two classifications, active searchlight and passive scanning, according to their modes of operation.

(*a*) ACTIVE SEARCHLIGHT TYPE (QDA).—The QDA equipment is placed in the active searchlight type depth-determining category because the equipment generates its own signal power and employs the searchlight method of searching. Using the target bearing information obtained from an echo-ranging equipment, the QDA equipment is trained to the bearing of the target and used to search in the vertical plane until the target is located. This equipment uses a crystal-type transducer. The transducer, often referred to as a "sword," is mounted with its largest dimension vertical. It is long and thin, and provides a rather wide horizontal but narrow vertical beam pattern, permitting accurate depression-angle determination.

(*b*) PASSIVE SCANNING TYPE (AN/SQR-4).—The Sonar Receiving Set AN/SQR-4 is designed primarily for use aboard vessels as a part of an integrated sonar system. The basic purpose of the equipment is to provide a means of determining the depth of an underwater object. The AN/SQR-4 equipment does not transmit a signal. It is always associated with an azimuth echo-ranging system which does transmit, and the echoes from the transmitted pulse of the azimuth system are utilized by the AN/SQR-4. The display circuits of the AN/SQR-4 are synchronized with the display circuits of the associated azimuth system. An audio system is provided, to obtain more detailed information on a particular target at any depression angle desired. The AN/SQR-4 is termed "passive" equipment because it depends on the transmitted signal of another equipment, and "scanning" equipment because it receives on all bearings simultaneously rather than at a particular bearing, as with searchlight operation.

(3) SONAR RESOLVING EQUIPMENT.—Sonar resolving equipment is designed to integrate information supplied by companion sonar equipments. A representative resolving equipment is the OKA-1. This resolving equipment is not directly concerned with the transmission or reception of underwater sound. It functions to provide the horizontal range of a target so that this information is available to determine the time for release of a barrage in an antisubmarine attack. In addition, the OKA-1 resolving equipment supplies range and rate data to an Attack Director for use by that equipment in the solution of attack problems.

In order to perform the above computations, the OKA-1 resolving equipment must be supplied with information from companion sonar equipments

in the form of sonar range and target depth. Synchronization of keying and other control information and functions of the companion sonar equipments are controlled by the resolving equipment. In addition to integrating this information, the OKA-1 resolving equipment also supplies rate-aided information to the depth-determining equipment, to assist the operator of that equipment to remain on-target in the late stages of an attack.

(4) SOUNDING EQUIPMENT. — Sonar sounding equipment is designed to determine the water depth beneath the hull of a vessel. The equipment operates by emitting a pulse of ultrasonic energy into the water and measuring the time required for the pulse to travel to the bottom and return. A representative sounding equipment is the AN/UQN-1B. This sonar sounding equipment consists of a sonar transducer and a receiver-transmitter. The transducer consists of an array of ammonium dihydrogen phosphate (ADP) crystals in a pressure-tight, flanged housing. The housing is designed for flush mounting in a standard hull ring in the bottom plating of a surface vessel, or outside the pressure hull of a submarine. This transducer, when transmitting, converts the electrical energy of the transmitter into underwater mechanical energy. This energy is directed downward, and upon striking the bottom, is reflected back. Upon striking the transducer, it is converted to electrical energy and amplified by the receiver. The received energy, or echoes, are indicated by two methods, as described below.

(*a*) RECORDER. — The recorder allows the receiver output to be visible on an electrically sensitive paper as a plot of depth below the vessel versus time. The plot on the chart paper becomes a representation of the contour of the bottom when the surface vessel proceeds at a constant speed and in a straight line.

(*b*) DEPTH INDICATOR.—Depth indication on the 100 foot or 100-fathom range is obtained on the face of a three-inch cathode-ray tube. These ranges are presented by means of radial modulation of a circular sweep. Both the transmitted pulse and the returning echo cause a radial modulation. The relative positions of these two radial modulations, when converted from time to feet or fathoms, indicates the water depth below the vessel.

(5) UNDERWATER COMMUNICATIONS.

(*a*) CW.—Most echo-ranging sonar equipments are provided with a means of underwater c-w communication. An example of such an equipment is Azimuth Scanning Sonar Set AN/SQS-1. The equipment is placed in normal operating condition with one exception, the transmitter keying relay, which is disabled. During normal operation, the keying circuits generate a d-c pulse having a length of either 12 or 35 milliseconds. This pulse is applied to the transmitter keying relay coil. During the time the relay is energized, the grids of the oscillator-converter and buffer-amplifier tubes are ungrounded, thereby permitting the tubes to operate and supply a signal to the following stages. During hand-key operation, the transmitter keying relay remains energized as long as the hand key remains depressed. This hand-key operation makes underwater communication possible by giving the operator direct control of the transmitter keying and pulse length.

(*b*) VOICE.—A typical underwater voice communication equipment is the Sonar Set AN/UQC-1. This sonar set is a single-sideband, suppressed-carrier receiver-transmitter designed to provide communication between submarines and surface vessels at ranges up to 12,000 yards, or beyond under favorable sonar conditions. Since the medium of transmission is water, where electromagnetic wave propagation, as used in radio and radar, is so limited in range as to be impracticable, sound waves, which are mechanical vibrations, must be used as a means of transmission of intelligence. A transducer is employed to convert the electrical impulses to mechanical vibrations. The electronic system converts voice frequencies to the upper sideband frequencies of an 8.0875-kc carrier wave. The audio frequencies from 250 cycles to 3000 cycles are converted to the upper sideband frequencies of 8338 cycles to 11,088 cycles. The carrier suppression and lower sideband elimination is accomplished by a balanced modulator and a bandpass filter. The carrier is reintroduced after reception of the signal and then converted to voice frequencies by demodulation. Basically, the microphone converts the audio signal into electrical impulses which are then amplified by the speech amplifier. The output from the speech amplifier is clipped by the clipper to maintain a constant output level. The modulator heterodynes the input signal with the 8.0875-kc oscillator signal and removes the lower sideband and the carrier frequencies. The driver amplifier amplifies the upper sideband and provides enough power to drive the power amplifier. The power amplifier drives the transducer, which converts the signal into acoustical energy in the water. On reception the transducer converts the acoustic signal in the water into electrical signals which are amplified by the receiver amplifier and then heterodyned in the demodulator with the 8.0875-kc signal to separate the intelligence. The driver amplifier raises the level of the demodulated wave before it is sent to the speaker for conversion to acoustic waves.

b. SONAR SYSTEM FUNDAMENTALS.

(1) TRANSMITTER. — The signal-producing equipment, normally called the "transmitter" or "driver," figure 3-123, basically consists of an oscillator producing a signal of proper frequency, and an amplifier to raise the power of that signal

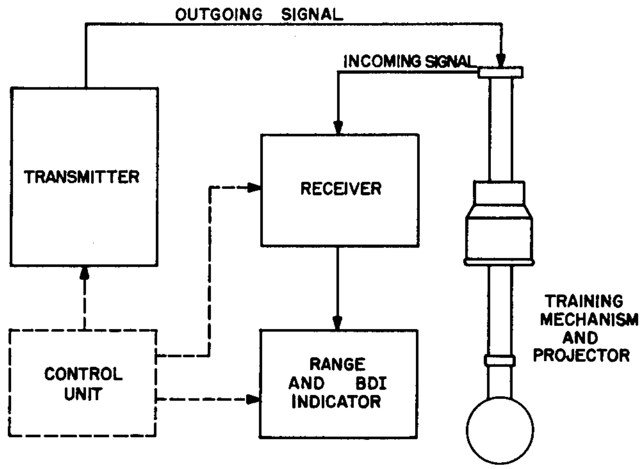


Figure 3-123. ***Block Diagram of a Basic Echo-Ranging Sonar System***

to the proper level for projection by the transducer. During transmission, ultrasonic energy originates in a crystal-controlled or inductance-capacitance tuned master oscillator of the transmitter. The duration of time during which the oscillator functions is controlled by the requirements of the range and the type of operation employed. The pulses formed by the oscillator occur at a repetition rate which is normally controlled by the range scale being used by the operator. The longer the range being employed, the lower the pulse repetition rate. This keying pulse, of proper duration and frequency, is amplified to an adequate power level and fed to a transducer.

(2) PROJECTOR.—The function of a projector, or transducer, is to serve as a converter of energy. A transducer, when acting as a transmitter, converts electrical energy into acoustical energy, and when serving as a receiver, converts acoustical to electrical energy. Transducers are divided into two general categories, magnetostriction and piezoelectric, according to their methods of construction.

(*a*) MAGNETOSTRICTION.—In a magnetostriction-type transducer the ends of several hundred nickel tubes are embedded in a steel plate or diaphragm. Each tube has a coil placed around it. These coils are arranged in a series-parallel circuit, and are fed with a signal of supersonic (a-c) frequency from the driver. When made to contract and expand in the alternating magnetic field created by the a-c in the coils, the nickel tubes transmit mechanical vibrations to the diaphragm. The diaphragm in turn transmits them to the fluid in the sonar dome. Then the sound vibrations pass through the sound window of the sonar dome into the surrounding water in a beam-like pattern. As a receiver, the magnetostriction transducer works in reverse. The diaphragm vibrates when struck by a supersonic signal from the water, and the vibrations are communicated to the nickel tubes. As the tubes expand and contract in length, they change the magnetic field about them. The changes in the magnetic fields in turn induce alternating voltages in the coils, and these voltages are transmitted to the receiver for amplification.

(*b*) PIEZOELECTRIC.—A piezoelectric-type transducer employs crystals as the frequency-sensitive devices. Several hundred crystal blocks, formerly made from Rochelle salts but of later years, from ammonium dihydrogen phosphate (ADP), are anchored on a diaphragm. Each crystal block has metal electrodes mounted on two of its opposing faces. The crystal assembly is housed in a chamber filled with castor oil, which as a medium for sound transmission is almost identical with sea water. The oil also keeps the crystals from contact with atmospheric moisture, which would quickly impair their operation. The crystals are connected in a series-parallel circuit and are fed with a supersonic (a-c) signal from the driver. When an alternating voltage is applied to the electrodes, the crystals contract and expand in length repeatedly. The vibrations of their free ends are much greater in scope than the vibrations they transmit to the diaphragm. Since it is not practical to amplify the vibration by increasing the applied power beyond a certain strength, for fear of breaking the crystals, it is necessary to make the most of the strongest vibrations present in the assembly for signalling purposes. The free ends of the crystals are therefore placed in direct contact with the castor oil. From the castor oil the vibrations pass through the rubber window of the sonar dome and out into the sea water in a beam-like pattern. Conversely, when the piezoelectric system acts as a receiver, the incoming signals strike directly on the free ends of the crystals. Because of the inertia of the diaphragm back of the crystals, the vibrations cause the crystals to contract and expand in length. The resulting changes in potential between their faces are passed on from the electrodes, and are amplified and converted into audible and visual signals by the receiver.

(*c*) CHARACTERISTICS.—Magnetostriction transducers are capable of handling higher power and vibration shocks than the crystal-type transducer, and are therefore used in installations where the operation of the sonar system requires that these factors be taken into consideration. The piezoelectric-type transducers are more sensitive and are considered rather fragile, and therefore are employed where low transmitting power and high receiving sensitivity are required. As a general rule of thumb, sonar receiving systems use crystal-type hydrophones (receiving only); echo-ranging and depth-determining equipments use either crystal or magnetostriction-type transducers (transmitting and receiving); and some

special-purpose communication and testing equipments use magnetostriction projectors (transmitting only).

(3) RECEIVER.—The principal function of a sonar receiver is to accept a supersonic signal from a transducer or hydrophone, and amplify and convert that signal into useful information. When a signal is to be heard in the supersonic frequency range, some method must be used to bring it into the audible or sonic range. This is accomplished by heterodyning in the receiver. See figures 3-126 and 3-129 for the block diagram of a sonar receiver. Usually there is a broad-band amplifier stage at the receiver input. This is followed by a filter system and an attenuator. The signal is then fed into the first mixer, where it is mixed with the output of a variable-frequency oscillator. The tuning of this oscillator provides for the adjustment of the receiver to various input frequencies. The signal from the mixer stage is amplified through an intermediate-frequency amplifier similar to that of any superheterodyne radio or radar receiver. This intermediate frequency is then fed into a second mixer, where it beats with a second oscillator to give an output in the audible frequency range. This converting system is used in addition to the regular audio amplification of the receiver, which drives the speaker.

(4) INDICATORS.—Indicators, as used in sonar, have three basic functions, as follows: To convert the travel of an underwater sound signal (time required to travel to a target and return) to range, in either feet, yards, or miles. To display a visual pattern from which the direction (azimuth) of a target may be determined. To indicate on-target or off-target operation (bearing and depth deviation).

Two methods are widely used to accomplish these purposes—the mechanical and the electronic method. These are described below.

(*a*) MECHANICAL. — The mechanical method employs a mechanical element which moves at a constant speed; the transmission of a given signal and the reception of its target echo are indicated at two points on the surface of the element, which is calibrated in feet, yards, or fathoms. Thus, the time difference is converted to a range indication. Some types of mechanical indicators employ a rotating disk, which is so constructed as to key the transmitter at the zero point of the disk; the returning echo illuminates a point on the disk. Since the disk is calibrated in feet, yards, or fathoms, the sound-pulse transit time is converted to distance. In some types of mechanical indicators, a metal belt or apron is driven at a constant speed. This belt has an aperture backed by a neon tube. The point at which a returning echo is received is indicated on a scale above this belt when the neon tube is ignited and the light allowed to shine through the aperture in the belt. The sound pulse is transmitted when the aperture is at the zero point of the scale. Another type of mechanical indicator is one which records the distances by means of a movable stylus and a constant-speed graph. The methods used to record on the paper vary, but the most common is the electrochemical method, in which a chemically treated graph paper passes over a charged plate. The recording stylus has a polarity opposite that of the plate. The electric current flowing from the stylus to the plate, through the graph paper, burns a record on the paper. Because a continuous recording is made, the total information may be studied and evaluated at a later time. In sounding operations, these recordings, when taken under the proper conditions, may actually portray the terrain below the water.

(*b*) ELECTRONIC.—Electronic indicators make use of a cathode-ray tube. Any difference that may exist in the different types of electronic indicators deal only with the type of information being portrayed. The methods of portraying different types of information are as follows:

1. DEPTH.—A J-scan is generally used to convert time to depth, and the calibration may be in either feet, yards, or fathoms. The J-scan is a sweep which produces a circular range scale near the circumference of the cathode-ray tube.

2. RANGE AND BEARING.—A spiral scan is generally used to portray range and bearing. This type of scan produces a plan (polar) view of the surrounding area being scanned.

3. ON-TARGET INDICATOR.—An A-scan is generally used to obtain indications of on-target operation. This may consist of a base line, either vertical or horizontal, and is generally used with BDI and DDI equipment. Two signals along one base line are made to coincide to indicate on-target operation.

(5) BEARING-DEVIATION INDICATOR.—The function of a bearing-deviation indicator is to visually indicate to an operator whether a target is on the center bearing of the transducer or is to the left or right of center bearing. On sonar equipments utilizing a bearing-deviation-indicator circuit, the transducer is "split" into two halves, either electrically or mechanically. These two halves work together when transmitting signals, but separately when receiving them. The small difference in time of arrival of an echo, from a target to the left or right of the transducer bearing, upon the two halves of the transducer is made to affect the BDI trace so as to show clearly whether the transducer is trained directly upon the target or slightly to the left or right. The BDI circuits require separate echo currents from the right and left sides of the transducer. The currents from the right and left halves of the transducer which are fed to the BDI circuits are of

equal amplitude, no matter whether the transducer is trained directly on the target or is trained a few degrees to the right or left of the target. Although always equal in amplitude, the two echo currents differ in phase according to the bearing of the target relative to the transducer bearing. The BDI circuit makes use of this phase difference to give a deflection to right or left of center on the BDI trace when the target is a few degrees to the right or left of the transducer bearing. The echo currents from the halves of the transducer are normally fed through an input transformer or transformers. The secondary voltage of these transformers is amplified in two input amplifiers. The amplifiers also act as a buffer stage to isolate the transducer from the "lag line," to which the output of the amplifiers is applied. The lag line delays or advances the alternating currents passing through it and makes the phase difference between them smaller or greater. The lag line causes one of the modulator tubes to get a stronger signal than the other, depending on whether the target is to the right or left of the transducer bearing. The lag-line signal and the output of a local oscillator are made to beat in two modulators and produce an intermediate-frequency signal. A 400-cycle oscillator switches on first one modulator and then the other. The output of the modulator is passed through an i-f stage, or stages, and then applied to a demodulator. The demodulated signal is then applied to an audio amplifier. The signal is amplified in the audio amplifier, and then part of the amplified signal is applied to a phase-sensitive detector and part is applied to a diode rectifier, the output of which is filtered and applied to a brightening circuit of the BDI indicator cathode-ray tube. In addition to the output of the audio amplifier, a portion of the 400-cycle oscillator signal is applied across a limiter tube which aids in distinguishing the phase relationship of the two input signals to the transducer, thus determining whether the bearing of the sound signal is to the right or left of the transducer bearing. After passing through a filter, the output of the phase-sensitive detector is applied to the horizontal-deflection circuit of the BDI indicator cathode-ray tube.

3-13. SONAR SYSTEMS—OVER-ALL PERFORMANCE CHECKS.

a. EXTERNAL FACTORS AFFECTING PERFORMANCE.—Numerous conditions other than the performance of the actual sonar equipment affect the over-all performance of a sonar system. The following factors should be taken into consideration when evaluating an over-all performance check.

(1) WATER CONDITIONS.—The ocean, considered as a medium for the transmission of sound, is far from an ideal medium. It is not infinite in extent, being bounded by the bottom and the surface. It is not similar in composition at all levels and locations; the upper layers are usually warmer than the lower ones, and near large rivers may be less saline. For both reasons the water is less dense in the upper regions. The temperature and salinity may change also in a horizontal direction. Thus, a sound wave propagated through the ocean is distorted from the spherical shape that is characteristic of a small source in an ideal medium. Other less obvious properties of the ocean contribute to making the propagation of sound waves difficult. As a sound wave travels outward from a source in the sea, some of the energy is converted into heat by friction, because of the viscosity of the water. This process is called absorption. Another portion of energy goes into the production of secondary wavelets, which travel in directions other than that of the primary wave. This is the phenomenon called scattering. A more general term, embracing both absorption and scattering, is attenuation.

(2) TURBULENCE.—This is the general term applied to noises which affect the reception of sonar targets. These noises can be divided into two general classifications, background and reverberation, as defined below:

(*a*) BACKGROUND NOISE.—Background noise includes extraneous sounds of various kinds which are subdivided into three categories, as follows:

1. SELF-NOISE.—Self-noise is produced at or on own ship; and stems from the following causes: motion of the ship and/or motion of gear relative to the water (that is, if the ship is stationary, the waves move past the transducer); mechanical vibrations incident to operations aboard own ship, producing sound waves that are picked up by the hydrophone; and stray noises caused by operation of the ship's power system and electrical machinery.

2. AMBIENT NOISE.—Ambient noise is produced at a distance from own ship, and stems from the following causes: Sea noise (principal cause unknown), heard even in deep water; rain, surf, and whitecaps are occasional causes. Biological noise; certain shrimp, fish, etc, produce sounds that are audible on sonic and ultrasonic equipments. Traffic noise, caused by ship traffic, and, in or near harbors, by industrial operations.

3. TARGET NOISE.—Target noise is produced at the target. This is a wanted sound in listening equipments but an unwanted background when echo-ranging, and may prevent accurate determination of the range of the target.

(*b*) REVERBERATION.—Reverberation noise is inherent in all echo-ranging operations, and is caused by the scattering of the emitted

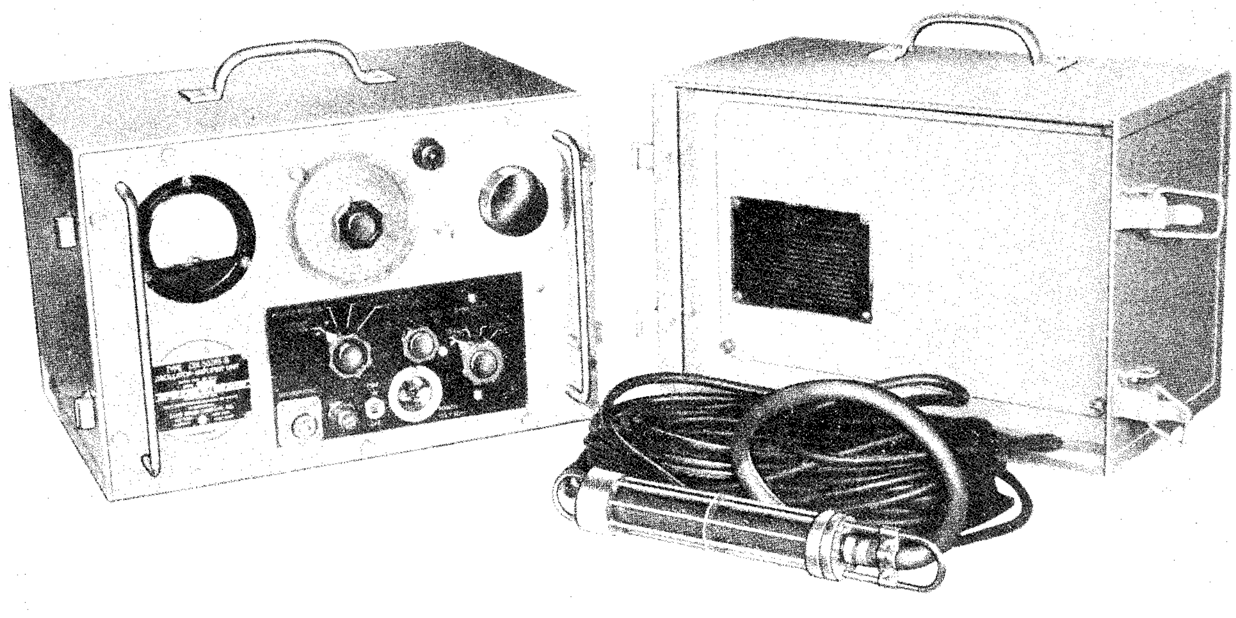


Figure 3-124. Sonar Portable Testing Equipment Navy Model OCP-3

sound as a result of irregularities of the sea bottom, irregularities of the sea surface, and unknown scattering mechanisms widely distributed throughout the sea.

b. INTERNAL FACTORS AFFECTING PERFORMANCE.—Various conditions within the equipment contribute to the over-all performance of a sonar system. A complete performance check should include the checks listed below.

(1) DRIVER POWER OUTPUT.—This check should be made to ascertain the amount of r-f power being delivered by the driver (transmitter) to the transducer. Various methods are available for performing this test, depending upon the specific equipment upon which the test is to be made. Information is given in paragraph 3-15.

(2) RECEIVER SENSITIVITY.—Sensitivity measurement of the receiver will furnish accurate information in respect to the over-all performance of the receiver. A decrease in efficiency to the point of lowered performance would be apparent in a sensitivity measurement, and steps should be taken to return the receiver to peak efficiency. Methods of performing a sensitivity measurement both on the receiver individually and on the over-all receiving system are discussed in paragraph 3-14.

(3) KEYING CIRCUITS.—Accurate keying, controlling, and timing circuits are vital to the satisfactory performance of a sonar system. Operation of a complete sonar system at times involves the use of numerous companion units in addition to the basic sonar equipment, such as, resolvers, computers, range recorders, and attack directors. In addition to controlling the driver, the keying circuits must provide synchronization of all the various functions of the equipment, including indicating circuits, ranging and depth-determining circuits, etc. The circuits which control the train, and the raising or lowering of the transducer, are vital to the operation of a sonar system. These circuits must be tested to complete an over-all performance check.

c. TEST MONITOR OCP SERIES. — Sonar Portable Testing Equipment Navy Model OCP Series (figure 3-124) is basically a transmitter and receiver of supersonic signals that can be accurately calibrated and measured. This equipment is discussed below.

(1) GENERAL.—The equipment consists of two major units, the oscillator/amplifier and the transducer. These units are provided with a carrying case for transporting them and their accessory cables. The testing equipment acts as a source of supersonic signal energy in the water for checking receiving-type circuits of the ship's equipment, and a means of receiving and measuring, relatively, any supersonic signal energy within its frequency and sensitivity range in the water, and thereby checking the transmitting circuits of the ship's equipment.

(2) USES.—Test monitor OCP series serves many useful functions in the performance testing of sonar equipments. Most tests made with the monitor equipment are systems tests, rather than individual unit tests. For instance, a receiving frequency-response measurement made with the monitor indicates the frequency response of the over-all receiving section (transducer, transmission lines, preamplifiers, and the receiver) rather

than the response of the receiver alone. Beside receiving and transmitting frequency measurements, the monitor may be used to make other tests, such as transmitting and receiving directivity patterns, transmitter (driver) output and frequency measurements, and receiver and transmitter tuning. These various measurements are described in more detail in paragraphs 3-14 through 3-16.

d. BEAM PATTERNS.—The plotting of beam patterns provides information on the transmitting and receiving characteristics of a sonar equipment. A certain minimum amount of directivity is required, to permit a sonar operator to determine the bearing of a target with any degree of accuracy. Plotting the beam patterns, transmitting and receiving, will indicate graphically to the technician whether or not sufficient directivity is being obtained to provide the accurate bearing information desired.

Beam patterns are divided into two categories, transmitting and receiving, and may be obtained as described below:

(1) TRANSMITTING DIRECTIVITY PATTERN.—Sonar Portable Testing Equipment Navy Model OCP Series may be used to complete this test. The sonar testing equipment, hereafter referred to as the monitor, should be installed as described in the instruction book for the monitor, and the beam pattern plotted as follows:

(*a*) Obtain a sheet of polar graph paper, as shown in figure 3-125. Indicate relative bearing of the monitor transducer from the ship's transducer.

(*b*) Set monitor selector switch to RECEIVE 63-123db. Depress driver test key and train ship's transducer for maximum indication on monitor output meter. Record this as maximum signal strength on the polar graph for future reference.

(*c*) Rotate the ATTENUATOR slip ring until the figure on the slip ring which corresponds to the output-meter reading (red) is opposite the ATTENUATOR knob pointer. Lock the slip ring in place. Rotate the ship's transducer through 360 degrees in 5-degree steps. At each 5-degree step, press the driver test key and observe the monitor output meter. With the driver test key depressed, adjust the ATTENUATOR control until the output meter indicates zero db, or as close to zero db as possible. Combine the readings of the output meter (red) and the ATTENUATOR slip ring.

(*d*) Place a dot on the graph paper on the radial line at which the reading was made, and at the distance from the center required by step (*b*).

(2) RECEIVING DIRECTIVITY PATTERN.—Sonar Portable Testing Equipment Navy Model OCP Series may be used for this test. Position

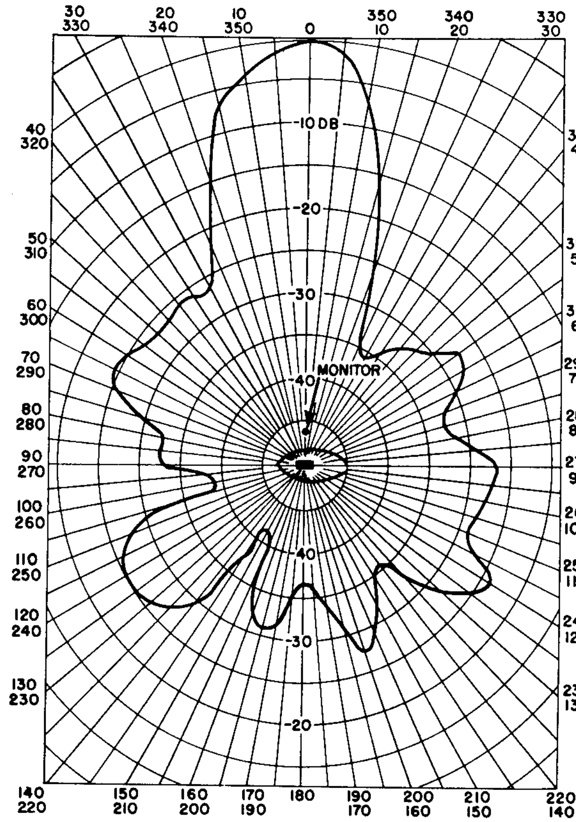


Figure 3-125. Typical Directivity Pattern

monitor transducer as directed in the paragraph above, and proceed as follows:

(*a*) Depress driver test key. Adjust ATTENUATOR control until the output meter indicates about zero db. Set selector switch to BEAT position, BAND CHANGE SWITCH to 5—11 kc, and FREQUENCY dial to 5 kc. With the driver test key depressed, tune FREQUENCY dial of the monitor slowly in a clockwise direction until a tone is heard. As the FREQUENCY dial setting is increased, this tone will change in pitch.

Note

Do not assume that the first beat note heard is the desired one. Tune through the entire range (4 bands) and select the strongest beat note, which should be the fundamental frequency.

(*b*) As soon as the correct beat note is heard, adjust the FREQUENCY dial until the pitch of the beat note is so low that it is almost inaudible. At this point the needle of the output meter will begin to vibrate. Carefully adjust the FREQUENCY dial until the vibrations of the meter needle can be reduced and finally stopped. This condition is known as "zero beat." The monitor is now tuned to the frequency of the driver. Record indication of monitor output meter.

(*c*) Set selector switch to SEND position. Adjust ZERO SET knob until monitor output

meter indicates zero db. Adjust monitor ATTENUATOR control to prevent overloading of the receiver. Rotate the ship's transducer through 360 degrees in 5-degree steps. At each 5-degree step, record the ship's transducer relative bearing and the indication of the receiver OUTPUT meter. Do not change any of the monitor or receiver settings during these measurements.

(*d*) Subtract monitor output meter indication recorded in step (*b*) from the receiver OUTPUT meter indication recorded in step (*c*), and plot the resultant figure at the appropriate bearings on the polar graph paper (figure 3-125). Indicate relative bearing of monitor transducer, maximum signal strength as recorded in step (*b*), and all pertinent information concerning the measurement, on the polar graph paper, for future reference.

3-14. SONAR TESTING—RECEIVER.

a. BDI RECEIVER TESTING.—Test methods for the BDI type sonar receivers are discussed in the following paragraphs.

(1) RECEIVER SENSITIVITY. — Test equipment required for a sensitivity measurement of a BDI type receiver, as shown in figure 3-126, are: a signal generator capable of being tuned to the frequency of the receiver and of delivering an output signal of one or more microvolts, unmodulated; and an output meter capable of indicating either 6 milliwatts or 1.9 volts, a-c. Reverberation control gain (RCG) circuits should be disabled for this test. The sensitivity should be measured as follows:

(*a*) Disconnect the input cable to the receiver. Set BALANCE control (R2) to the mid-position and AUDIO GAIN control (R3) to the maximum clockwise position. Adjust BFO FREQ. control (C1) for the proper BFO operating frequency (normally 800 cycles).

(*b*) Plug a set of headphones into the PHONE jack, and connect the output meter or a-c voltmeter being used across the secondary of the audio output transformer. Adjust REC. GAIN control (R1) to produce a noise level of 0.06 milliwatt or 0.19 volt, as indicated by the output meter.

(*c*) Connect the signal generator, using an impedance-matching hookup if required, to the input of the receiver. Tune the signal generator for maximum deflection on the output meter, reducing the output of the signal generator as required to prevent damage to the output meter.

(*d*) Adjust the output of the signal generator until output meter indicates 6 milliwatts or 1.9 volts. Receiver sensitivity is indicated by the signal-generator output in microvolts.

(2) BDI CHANNEL SENSITIVITY.—The operation of the receiver (BDI channel) may be tested as follows:

(*a*) Disconnect the input to the receiver and connect a signal generator, tuned to the frequency of the receiver, as described in the preceding test. Place the equipment in a "listening" condition and energize the BDI circuits. Adjust the brilliance and centering controls, and the REC. GAIN control (R1), for a horizontally centered, vertical trace, with 1/8 inch of visual noise on the trace. Adjust the signal generator to obtain 10 microvolts output, unmodulated.

(*b*) "Pulse" the output signal of the signal generator by keying the output lead, or by turning the plate voltage of the signal generator off and on. At the same time, adjust the BALANCE control (R2) so that the trace on the BDI indicator tube will deviate as little as possible from the straight vertical line.

(*c*) Adjust the signal generator for 1-microvolt output. Rotate the BDI switch from the OPERATE to LEFT position. As this is done the trace should shift 1/2 inch to the left of the original position of the trace. Now rotate the BDI switch to the RIGHT position; this should cause the trace to shift 1/2 inch to the right of the original position. The trace on the BDI tube should be as symmetrical as possible, and should not deviate by more than 5 percent. Any marked deviation from the original trace indicates faulty operation.

(3) BFO ALIGNMENT.—To align the beat-frequency oscillator, proceed as follows:

(*a*) Rotate the AUDIO GAIN control (R3) (figure 3-126) to maximum clockwise position. Set BFO FREQ. control (C1) to indicate the frequency normally used (usually 800 cycles).

(*b*) Connect a signal generator, adjusted to the frequency of the i-f amplifiers of the sound channel of the receiver, to the control grid of the second detector (V16). Adjust output signal of signal generator to approximately 0.1 volt. Plug a set of headphones into the PHONES jack of the receiver, and connect the output meter or a-c voltmeter being used across the secondary of the audio output transformer. Adjust the internal master tuning control (other than front panel, BFO FREQ. control (C1) adjustment) until maximum indication is obtained on the output meter.

(*c*) The BFO frequency must be higher than the incoming signal. This can be checked by decreasing the signal-generator frequency used in step (*b*) by 1000 cycles. When this is done the audio output frequency should increase in pitch, the audio frequency now being the BFO frequency plus 1000 cycles. If the pitch should be lower when the signal-generator output frequency is reduced, this indicates that the BFO is tuned below the incoming signal frequency and should be readjusted.

(4) R-F ALIGNMENT.—The r-f section of

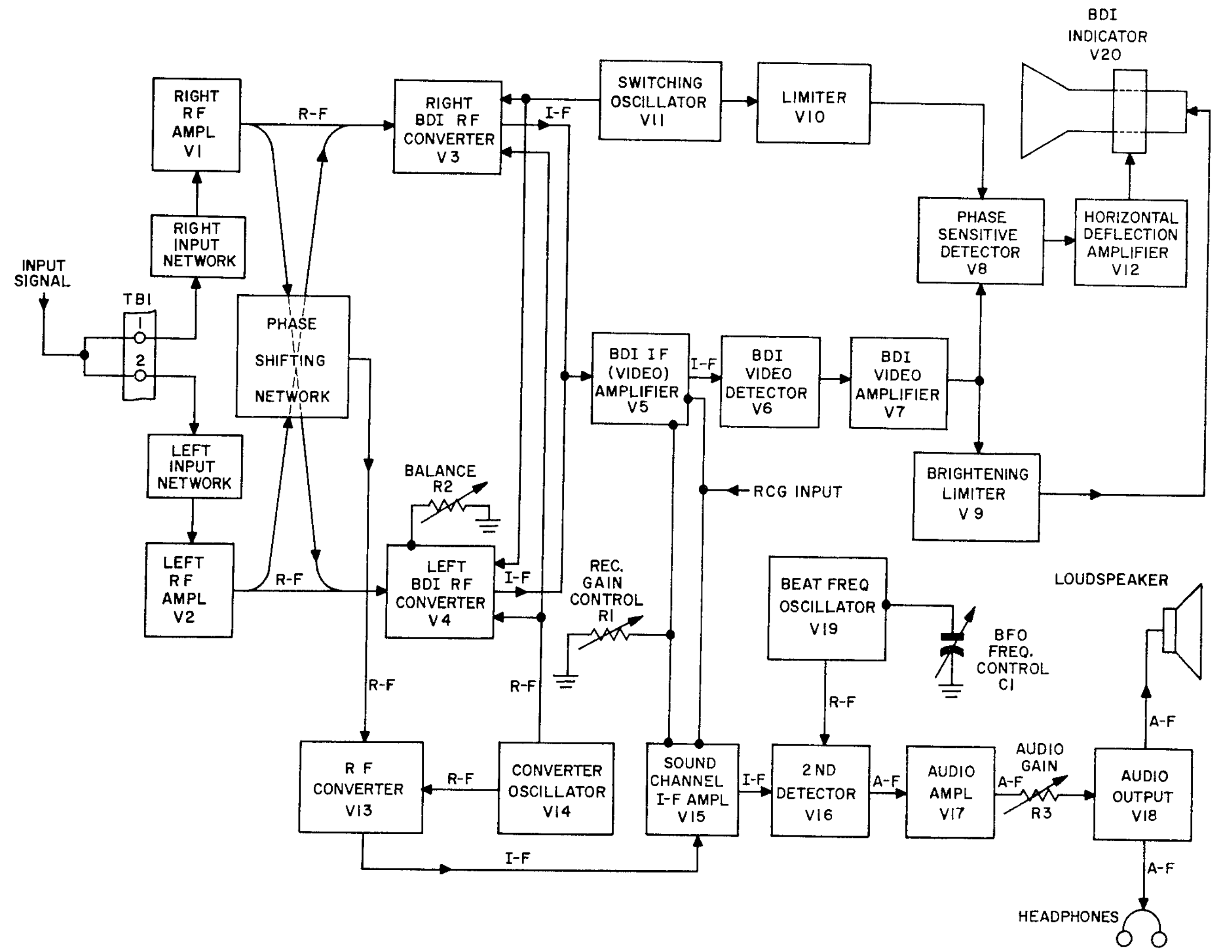


Figure 3-126. BDI Receiver Block Diagram

the receiver (figure 3-127) may be aligned as follows:

(*a*) Make the following preliminary settings of controls: REC. GAIN control (R1) to maximum clockwise position, BFO FREQ. control (C1) to normal operating position, and AUDIO GAIN control (R3) to maximum clockwise position. Plug a set of headphones into the PHONES jack of the receiver, and connect an output meter across the secondary of the audio output transformer. Disconnect the input to the receiver at terminal board TB1, terminals 1 and 2. Set the BDI switch to the BALANCE position, and set the BALANCE control (R2) to the mid-position.

(*b*) Set the receiver tuning control at its lower limit. Connect the signal generator, adjusted to the low-limit receiver frequency, to the control grid of the right BDI r-f amplifier tube (V1). Adjust the trimmer or padder, provided across the main tuning component of the converter-oscillator (V14), for proper oscillator tracking at the low-frequency end, until maximum indication is obtained on the output meter.

(*c*) Set the receiver tuning control to its upper limit. Adjust the signal generator to the upper-limit receiver frequency. Adjust the trimmer or padder, provided for proper oscillator tracking at the high-frequency end, to obtain maximum indication on the output meter.

(*d*) Repeat steps (*b*) and (*c*), several times, until proper tracking is obtained between the high-frequency and low-frequency ranges of the receiver. Record output-meter readings at the high and low frequencies.

(*e*) Transfer the signal generator to the control grid of the left BDI r-f amplifier, and note output-meter indications at the frequencies used in steps (*b*) and (*c*). Compare these readings with the readings recorded in step (*d*). There should be very little difference between these two sets of readings; a large difference indicates that one section is unbalanced with respect to the other, in which case balancing should be attempted by substituting tubes until fairly equal readings are obtained.

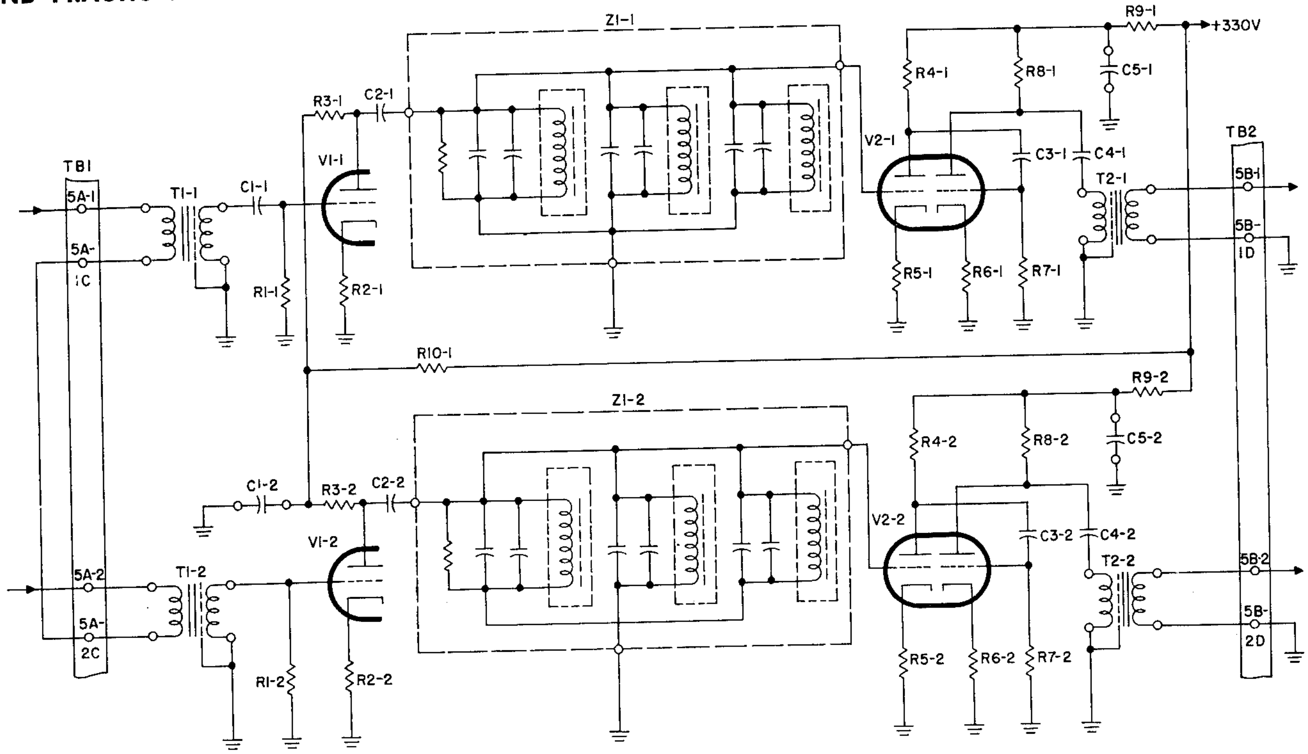


Figure 3-127. Simplified Schematic of Two Preamplifier Stages

(*f*) Connect the signal generator to the receiver input at terminal board TB1, terminal 1. Adjust the signal generator to the low-limit receiver frequency, and then to the high-limit receiver frequency, adjusting the right r-f amplifier input network for maximum indication on the output meter at each limit. Repeat this process until no interaction occurs between the two adjustments.

(*g*) Connect the signal generator to terminal 2 of TB1, and repeat the procedure outlined in step (*f*) for the left r-f amplifier (V2). Reconnect the input leads to the receiver.

(5) I-F ALIGNMENT (SOUND CHANNEL).—Make the following preliminary settings of controls: REC. GAIN control (R1) and AUDIO GAIN control (R3) to maximum clockwise position, and BFO FREQ. control (C1) to normally used frequency setting. Proceed with the alignment as follows:

(*a*) Connect an output meter across the secondary of the audio output transformer. Remove the converter-oscillator tube (V14).

(*b*) Connect a signal generator, adjusted to the intermediate frequency of the receiver, to the control grid of the r-f converter tube (V13). Adjust the i-f transformers at the input and output of the i-f amplifier tubes for maximum indication on the output meter. Remove the signal generator and replace the converter-oscillator tube.

(6) I-F ALIGNMENT (VIDEO CHANNEL). — The intermediate-frequency stages (video channel) of the receiver may be aligned as follows:

(*a*) Energize the BDI circuits of the receiver, set BALANCE control (R2) (figure 3-126) to mid-position, and REG. GAIN control to maximum clockwise position. Connect a vacuum-tube voltmeter between the plate of the last i-f stage and ground.

(*b*) Connect a signal generator, adjusted to the intermediate frequency of the receiver, through a coupling capacitor to the plate of either the left or right BDI r-f converter tube, V3 or V4. Adjust the i-f transformers at the input and output of the i-f amplifier stages for maximum indication on the vtvm.

(7) BDI SWITCHING-OSCILLATOR ADJUSTMENT.—Under normal conditions, the switching oscillator will not require adjustment. However, should any components in this circuit be replaced, it may be necessary to readjust the oscillator to its proper operating frequency. A vernier frequency control is normally provided for this adjustment, but is usually an internal, locked screwdriver control. The oscillator may be adjusted as follows:

(*a*) Remove the right and left BDI converter tubes, V3 and V4. Connect the vertical-input signal jack of an oscilloscope to the screen grids of the converter tubes.

(*b*) Connect the output of a calibrated beat-frequency oscillator, adjusted to the frequency at which the switching oscillator should function, to the horizontal-input jacks of the oscilloscope.

(*c*) Adjust the frequency vernier control to obtain a circular trace on the screen of the oscilloscope. Lock the vernier tuning control.

b. SCANNING RECEIVER TESTING.—Test methods for the scanning type sonar receivers are discussed in the following paragraphs.

(1) PREAMPLIFIER (AF-RF AMPLIFIER) MEASUREMENT.—The transducers employed in scanning type sonar systems are divided into numerous segments, each segment acting independently of the others. Each segment, of which there are 48 in such equipments as the AN/SQS-1 and the QHB-1, has an associated preamplifier. A typical preamplifier, two of which are shown in figure 3-127, is comprised of an input amplifier, a bandpass filter, and an output amplifier. The sensitivity of the preamplifier should be measured, and simultaneously the preamplifier may be checked to ensure that the outputs of the preamplifiers are equal in amplitude and of the correct phase relationship to each other. This may be accomplished as follows:

(*a*) Connect a signal generator, adjusted to the operating frequency of the sonar system, to the inputs of preamplifiers No. 1 and No. 2 (V1-1 and V1-2) at terminals 5A-1 and 5A-2, respectively.

(*b*) Connect an electronic voltmeter, using the 1-volt scale, across the output of preamplifier No. 1 at terminals 5B-1 and 5B-1-D. Adjust the output voltage of the signal generator until the electronic voltmeter indicates 0.5 volt. Record the output voltage of the signal generator and the indication of the electronic voltmeter.

(*c*) Connect the X-axis terminals of an oscilloscope to terminals 5B-1 and 5B-1-D so that preamplifier No. 1 will cause horizontal deflection, and adjust the oscilloscope to produce a total deflection of 20 divisions.

(*d*) Disconnect the X-axis terminals of the oscilloscope, and connect the Y-axis terminals to terminals 5B-1 and 5B-1-D, so that preamplifier No. 1 will cause vertical deflection; adjust the oscilloscope to produce a total vertical deflection of 20 divisions.

(*e*) Reconnect the X-axis terminals as in step (*c*). With both the X-axis and Y-axis terminals connected to the output of preamplifier No. 1, the resultant screen pattern should appear as a single diagonal line (figure 3-128) joining the lower-left and the upper-right corners of the 20-division square.

(*f*) Remove the voltmeter and the Y-axis oscilloscope lead from terminals 5B-1 and 5B-1-D, and connect them across the output of preamplifier No. 2 at terminals 5B-2 and 5B-2-D. The electronic voltmeter should indicate 0.5 volt ±0.12 volt, and the oscilloscope should show a diagonal line as in step (*e*) or a narrow ellipse whose sides are separated by not more than three divisions, as measured on the vertical axis.

(*g*) Check the remainder of the preamplifiers in a similar manner, with the signal generator simultaneously furnishing the input to both preamplifier No. 1 and the preamplifier being tested. The X-axis remains connected to the output of preamplifier No. 1 throughout the tests, while the Y-axis and the electronic voltmeter are connected to the particular preamplifier being tested. This method provides a comparison of all the preamplifiers with respect to the first preamplifier.

(2) VIDEO CHANNEL SENSITIVITY.—The sensitivity measurement of the video channel of a scanning type receiver (figure 3-129) is very similar to the i-f and video sensitivity measurement for any other receiver. A calibrated signal of the proper frequency is fed into the video section, and the output is measured. To ascertain that the signal generator is at the proper operating frequency, the following calibration may be made:

(*a*) Connect a signal generator, adjusted to approximately the operating frequency and with an output of 100 millivolts, to the vertical-input

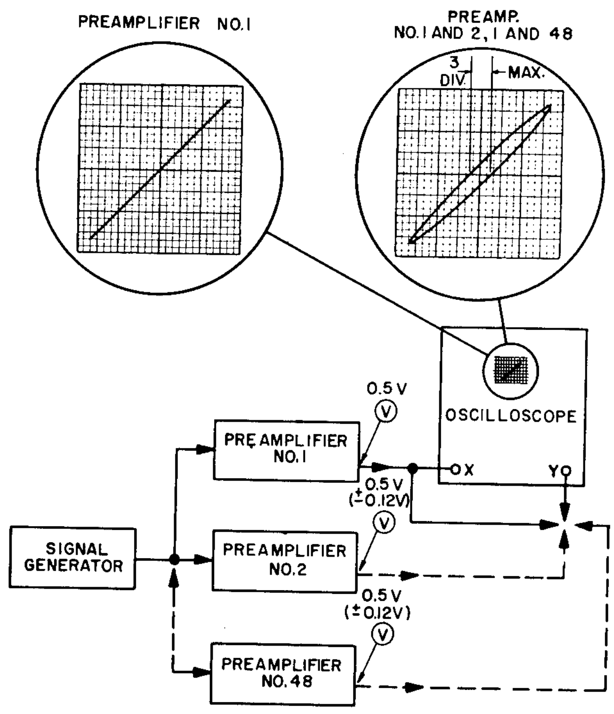


Figure 3-128. Preamplifier Test Assembly

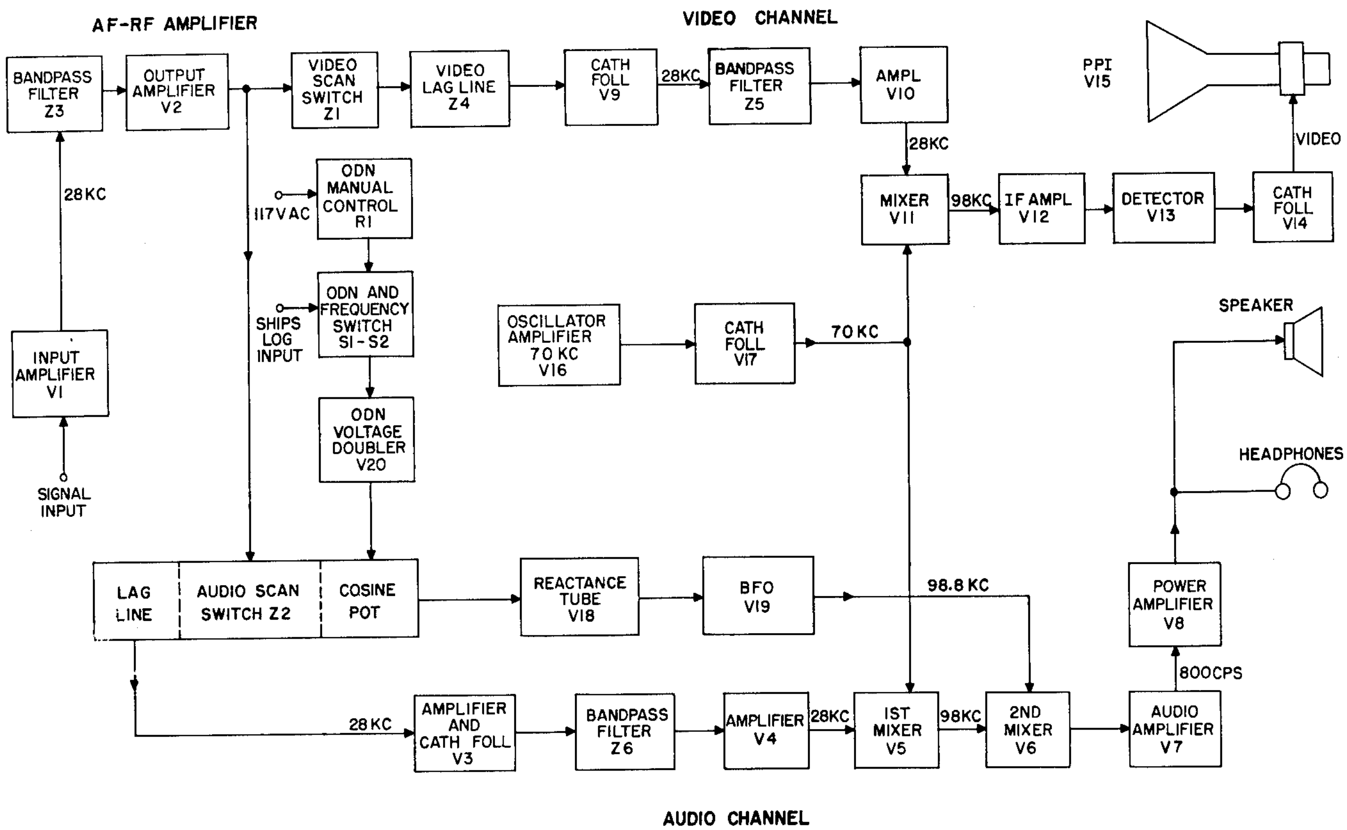


Figure 3-129. ***Block Diagram of Scanning Type Sonar Receiver***

jacks of the oscilloscope. Connect a signal voltage at the transmission frequency, possibly from a pin of the hand-key relay, to the horizontal-input jacks of the oscilloscope; disable the equipment in such a manner as to prevent transmission. Adjust the horizontal and vertical gain controls of the oscilloscope until a square, or nearly square, pattern is obtained on the oscilloscope. Slowly adjust the signal-generator output frequency until a stationary, or nearly stationary, circular pattern is obtained. This will indicate that the signal generator is adjusted to the transmission frequency.

(*b*) Now the signal generator may be used as a source of input signal, and should be connected to the input of the video channel at the video lag line. The output should then be measured, using an electronic voltmeter connected across the output of the video amplifier cathode follower (V14).

(3) AUDIO CHANNEL SENSITIVITY.—The sensitivity of the audio channel can be measured in a manner very similar to that used for the video measurement. The signal generator is adjusted to the transmission frequency in the same manner, but should be connected to the first audio amplifier (V3), and the output should be measured across the secondary of the audio output transformer.

(4) ODN OPERATION CHECK.—The performance testing of own doppler nullifier circuits will vary considerably in detail with each type of equipment, but fundamentally the tests are made as follows:

(*a*) If an attack director is employed in the system, disable it for this test, and place the equipment in a "listening" condition. Place the ODN switch in the manual control position, and set up an arbitrary speed, i.e., 40 knots, on the speed control. Adjust the receiver and audio gain controls to normal operating position. Set the BFO to operate at 800-cycle difference frequency.

(*b*) Train the transducer to zero degrees relative bearing, and note the pitch of the speaker tone. Train the transducer through 360 degrees of rotation, and note that the pitch of the speaker is maximum at 180 degrees bearing and minimum at zero degrees bearing. Train the transducer to 90 degrees relative bearing, and throw the ODN switch to "off". The pitch, an 800-cycle note, should not change. The same result should be obtained when the procedure is repeated at 270 degrees relative bearing.

c. FREQUENCY MEASUREMENT.—A frequency measurement of the receiving system may be performed by the use of Sonar Portable Test-

ing Equipment Navy Model OCP Series. This type of measurement will indicate the frequency of the complete receiving system rather than of the receiver alone. The monitor (OCP test equipment) should be installed as directed in the instruction book for the test equipment. Assuming that the monitor is properly installed and that the receiver is tuned to peak, the measurement may be made as follows:

(1) Set the monitor selector switch to SEND. Adjust the monitor FREQUENCY dial to approximately the frequency at which the receiver should be functioning. Set the receiver gain controls for normal operation. Adjust the monitor ZERO SET knob until the monitor output meter indicates zero db. Adjust the ATTENUATOR control until an indication is obtained on the output meter of the receiver. If the receiver does not have a self-contained output meter, one may be connected (preferably a meter calibrated in decibels) across the output of the receiver. Simultaneously set the ATTENUATOR for maximum output and adjust the receiver gain control for mid-scale deflection of the receiver output meter. Tune the monitor slowly until maximum deflection is obtained on the receiver output meter, reducing the receiver gain control as required, to prevent damage to the meter.

(2) Decrease the setting of the monitor ATTENUATOR dial by 6 db. If the output meter of the receiver falls back by more than 5½ db, the receiver is not overloading. If the output decreases by less than 5½ db, the receiver is overloading, in which case readjust the output-meter reading to mid-scale and decrease the ATTENUATOR dial another 6 db while observing for the proper decrease on the receiver output meter. Continue to reduce the ATTENUATOR dial, without changing the receiver gain controls, until the proper indications are obtained. Carefully retune the monitor for maximum deflection of the receiver output meter. Note the frequency of the monitor, which will indicate the frequency to which the receiver is tuned.

d. FREQUENCY - RESPONSE MEASUREMENT.—Upon completion of the receiver frequency measurement, the response of the receiving system may be plotted in the following manner:

(1) Obtain a sheet of linear rectangular graph paper, as shown in figure 3-130. Label the horizontal axis "SIGNAL FREQUENCY, KC" and number the horizontal axis for a frequency range of 2.5 kc, centered on the peak frequency noted in step (2) of the frequency-measurement procedure given above. Label the vertical scale "RELATIVE OUTPUT, DB", and number it so that the reading noted in step (2) of the frequency measurement is near the top of the graph and a range of approximately 30 db is obtained. Set the

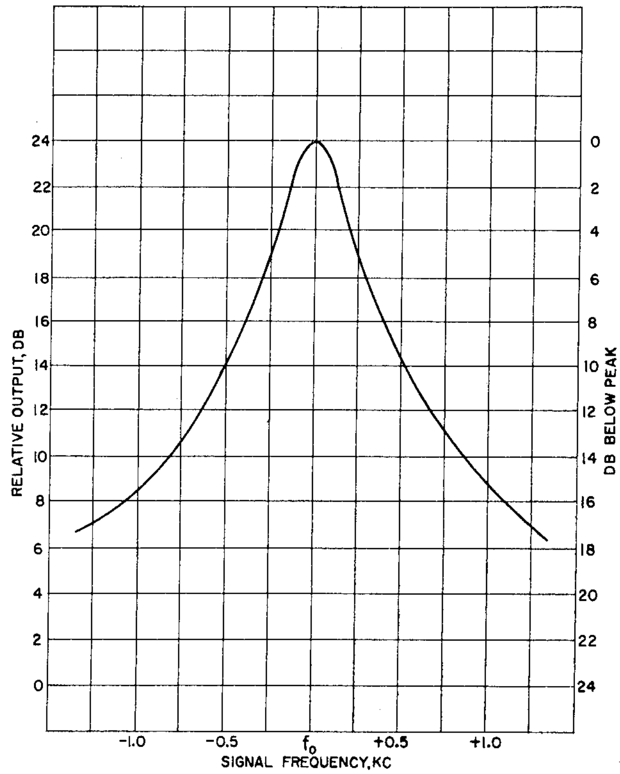


Figure 3-130. Graph of Sonar Receiver Frequency Response

monitor tuning dial to the lowest frequency indicated on the horizontal axis of the graph, and read the received signal strength from the receiver output meter. Record the receiver output-level reading on the graph paper by putting a dot at the point corresponding to the proper readings on the db scale and frequency scale.

(2) Increase the frequency of the monitor by 0.1 kc, and record the output of the receiver as in the preceding step. When approaching the resonant frequency of the receiver, 0.05-kc steps should be used, but near the limits 0.1-kc intervals will be sufficient. Label the graph with all the pertinent data concerning the test, such as receiver gain control setting, attenuator settings, monitor transducer location, frequency, bandpass or filter switch positions, etc.

3-15. SONAR TESTING—TRANSMITTER.

To achieve optimum sonar equipment performance, the transmitter must shape sound pulses at the proper frequency, of a correct amplitude and a definite repetition rate. Regularly scheduled tests should be performed to check on all these transmitter characteristics.

a. FREQUENCY MEASUREMENT. — The sonar transmitter should operate at a particular frequency with relation to its associated receiver. The most common piece of test equipment in use

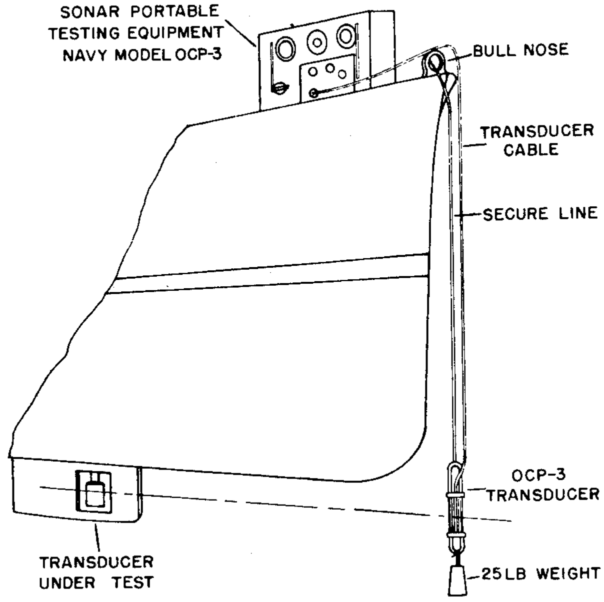


Figure 3-131. Sonar Test Monitor Installation

today, for frequency measurement, is Sonar Portable Testing Equipment Navy Model OCP Series. This equipment is designed to measure underwater sound intensity and its frequency, and also to generate its own test frequency signal, which is used for testing sonar receivers. For detailed operating instructions for this piece of test equipment, refer to Instruction Book NavShips 91601. To measure the sonar transmitter frequency, suspend the OCP transducer (figure 3-131) within the radiation pattern area of the ship's transducer under test. Train the ship's transducer to the estimated bearing of the OCP transducer, and press the sonar equipment test key. Set the selector switch of the OCP to RECEIVE 63-123 db position. The ship's transducer is now transmitting an underwater sound signal which is being received by the OCP test equipment. To verify proper placing of the test transducer, vary the depth of the OCP test transducer over a range of several feet until the point of highest output is indicated by the OCP output meter. To verify the correct positioning of the ship's transducer under test, vary the azimuth or the elevation of the ship's transducer (depending upon the type of equipment being tested) through its entire range until the point of highest output is indicated by the OCP test transducer. Now that the transducers have been properly oriented, proceed to measure the sonar transmitter frequency, as follows:

(1) At the OCP, with the selector switch set to 63-123, adjust the ATTENUATOR control until the output meter indicates zero db.

(2) Set the selector switch to BEAT.

(3) Set the BAND CHANGE switch to the frequency range of the signal being measured.

(4) Tune the FREQUENCY dial of the OCP slowly upward until a tone is heard. The OCP output meter will begin to fluctuate at this time. As the FREQUENCY dial of the OCP is turned, this tone will change in pitch, and the beat note will become lower. Keep turning the FREQUENCY dial until the beat note becomes inaudible (zero beat). At this point, the needle of the output meter will cease to fluctuate and will stand still. The frequency of the sonar transmitter can now be read on the FREQUENCY dial scale corresponding to the setting of the BAND CHANGE switch. The reading is accurate to within 2 percent or better.

b. POWER-OUTPUT MEASUREMENT. — A reduction in power, if not detected, will reduce the operating range of a sonar equipment and allow targets to go undetected. Power measurements at regular intervals will keep the transmitter operating at its maximum range. Power output may be indicated by various methods. In some sonar transmitters, the high voltage to the final amplifier stage is metered. Observing this voltage during transmitter keying provides an indication of power output. Refer to the applicable instruction book for correct indications. Observation of the voltage and current being applied to the final amplifier stage will indicate the power input to the final stage, from which the power output may be calculated. Another method of measuring power output is to use the OCP test equipment. The OCP test equipment will measure a certain underwater sound intensity in db, at a predetermined distance from the transducer under test. If this same measurement is taken at regular intervals and under the same conditions, a relative indication of power output of the sonar transducer will be obtained. The OCP is used in the following manner:

(1) Adjust the OCP test equipment in the same manner as for making frequency measurements.

(2) Combine the readings of the ATTENUATOR dial (RECEIVE scale) and the output meter (black) algebraically. This figure is the measurement of signal intensity in db of the transmitted sound.

c. KEYING TESTS.—Generally, the keying function of an active sonar equipment shapes the transmitted sound pulse and controls the length and the repetition rate of the pulse. The keying function may also switch the sonar equipment from transmit to receive at a predetermined moment. In sonar equipment having electronic indicators (cathode-ray tubes), the keying circuits may also be used to trigger the sweep circuits. In sonar equipment having mechanical-type indicators or recorders, the keying function is usually

controlled by the indicating device or recorder. To obtain maximum results from a sonar equipment, the pulse characteristics should be adjusted according to the directions in the applicable instruction book.

(1) SWEEP RATE.—Because the pulse (ping) repetition rate is exactly the same as the sweep rate, checking one will check out the other. This also holds true in the case of mechancial indicators. Sonar sweep rates are relatively slow, and may be checked by means of a stop watch. Refer to the applicable instruction book for exact adjustment procedures and specifications.

(2) PULSE LENGTH.—The range and power output are controlled to some extent by the pulse length. Long pulse length is desirable for maximum equipment range. For general search purposes, the longest available pulse length is used. For short range and for smaller targets, the shorter pulse lengths are utilized. Shorter pulse length also allows better definition of the searched area. On sonar equipment having electronic indicators, pulse length is usually checked on the indicator cathode-ray tube. In this method the pulse is allowed to modulate the cathode-ray tube and the pulse length is measured on the tube face as a certain length with respect to the sweep time. An adjustment is available for changing or adjusting this circuit. On the mechanical type of indicators or recorders, the spacing of contacts usually controls the pulse length, and is usually adjustable. On some equipment, the position of the keying contacts with respect to a tuning cam is changed. Because all types of sonar equipments have different pulse characteristics, reference should be made to the applicable instruction book for specific instructions.

d. VOLTAGE CHECKS. Voltage checks are a valuable aid in determining the condition of a sonar transmitter and also when trouble-shooting a defective sonar transmitter. Sonar transmitters having front panel meters are very easy to check. Whether a meter measures voltage or current, it will provide valuable information as to the operation of the metered circuit.

(1) PRIMARY VOLTAGE.—All sonar equipment except the portable type is a-c operated. The sonar transmitters have been designed to operate on a certain primary power input, and will not perform within their design capabilities unless this primary power is correct. The equipment design is such that a ten percent variation in primary voltage will be tolerated without noticeably affecting the equipment performance. In portable and in battery-operated equipment, d-c battery supplies should be checked periodically and exact battery replacements used when needed. Emergency sonar equipment, such as the AN/BQC-1, is battery operated, and the batteries should be checked regularly.

(2) D-C VOLTAGES.—In a-c operated sonar transmitters, the d-c voltages are provided by a-c operated rectifiers or by a-c operated motor-generators. When measuring the d-c output of these rectifiers or motor-generators, first check the primary power. Primary power with the allowable ten percent variation will produce a ten percent variation in its output, except in the voltage-regulated circuits. For this reason transformers are sometimes provided with adjustable primary windings. The adjustment is usually a variable tap, and should be adjusted for the line voltage being used. The filament transformers should be adjusted along with the power transformers for the same reason. Improper d-c voltage at the output of rectifiers is generally the result of weak rectifier tubes, or copper-oxide rectifier, whichever the case may be. In the case of copper-oxide rectifiers, aging of rectifiers is to be expected. For this reason, transformer taps have been provided to compensate for reduced voltage output.

A defective stage in a sonar transmitter will most likely be indicated by an erroneous voltage reading. Thus, measurement of voltages may be used for trouble-shooting a sonar transmitter. There are other troubles, such as an open coupling capacitor, which will not be indicated by voltage measurements.

(3) POLARIZING VOLTAGE (CURRENT).—Sonar transmitters using magnetostriction-type transducers must be provided with a polarizing voltage, if they are not of the permanent-magnet type. This polarizing voltage is used to create a magnetic field around each of the many nickel tubes. Each of the nickel tubes must be magnetized, to avoid operating at twice the transmitter frequency. The polarizing voltage is dc, and should be checked regularly. Refer to the applicable instruction book for the correct voltage and current requirements.

3-16. SONAR TESTING—TRANSDUCER.

Transducers, whether they be projectors or hydrophones, are subject to extremely adverse operating conditions. Transducers are exposed to collision and to chemical action of sea water. Some transducers are enclosed in a free-flooding sonar dome. The purpose of this sonar dome is to enclose the transducer in a streamlined structure containing "still" water, thereby reducing water turbulence at the transducer. Excessive water turbulence will interfere with the reception of underwater sound signals, and in the case of projectors, may distort transmitted sound patterns.

Excessive water turbulence may also be caused by scratches, dents, or marine growth on transducers or on the sound-transparent windows of sonar domes. These conditions should be corrected

as soon as possible, to obtain optimum sonar performance. A diver may be sent over the side to inspect sound domes and transducers for physical defects.

a. MARINE GROWTH.—The presence of marine growth on either transducer or sound dome will interfere with transmission and reception of sound, and may also cause excessive water turbulence. Marine growth should be removed carefully, in order to avoid damaging the sound dome, its transparent window, or the transducer itself. The sound dome usually has an access door, to aid in obtaining access to the transducer within.

b. DOME DAMAGE.—Sound domes may become damaged in several ways. Debris in the water, or very heavy seas may cause damage. Sound domes may also be damaged severely by anchor chains when a vessel is allowed to drag its anchor. Damage to sound domes usually cannot be repaired with the vessel afloat.

c. TRANSDUCER DAMAGE.—Damaged transducers may sometimes be repaired, depending upon the type of installation and the condition of the sound dome. Since most types of transducers are retractable, it may be possible to gain access to them for servicing. The procedure is not recommended for inexperienced personnel, for reasons seen in the following description. The sound dome surrounding the defective transducer must be in excellent physical condition, in order to withstand the water pressure. To gain access to the transducer, proceed as follows:

(1) Seal the free-flooding holes in the sonar dome, using soft wood plugs. This must be done by a diver from the outside.

(2) Carefully open the pressure valve at the sea chest to check for water pressure. If, after a few seconds, water pressure persists, the project should be abandoned. If the water pressure diminishes, the top of the sea chest may be removed very carefully and the transducer withdrawn and serviced.

(3) After repairs have been completed, and the sea chest reassembled, a diver should remove the soft wood plugs which were installed at the beginning of this procedure.

d. INSULATION TESTING.—In order to have proper transducer operation, electrical leakage between the cable conductors, the conductors and the cable shield, and the transducer windings and the transducer case, must be held to a minimum. An insulation resistance tester (megger) should be used for these tests. A resistance of more than ten megohms between any of the above mentioned points is sufficient for acceptable transducer operation. Insulation resistance of less than ten megohms indicates defective insulation or leakage of water into the transducer proper.

e. CONTINUITY TESTING.—Continuity tests will ascertain the presence of breaks in transducers and the connecting cables. Continuity will be obtained in magnetostriction-type transducers and also in some types of crystal transducers. (Some types of crystal transducers have a resistor connected in parallel with each crystal.) Most types of crystal transducers will not show continuity, but will show a capacitive effect when measured with an ohmmeter. Magnetostriction-type transducers usually have resistances below 50 ohms for each winding.

f. LEAK DETECTION.—Two types of devices are in use for the detection of water leakage in transducers. One type is made of two separate windings upon a coil form which has been coated with hygroscopic salts. One end of each winding is left open, and the other end is brought out to a lug. Any moisture or water present within the transducer will be absorbed by the hygroscopic salt coil form. The resistance of the coil form will decrease, and when measured at the two test lugs, will indicate a damp or leaking transducer.

The other type of leak detector is similar in construction to a salt water battery. The presence of salt water at the detector acts as the electrolyte of the battery, causing a voltage to be generated. The presence of a voltage at the test lugs indicates a leaking transducer. Some transducers have no built-in leak detectors, and must be opened for inspection if continuity or resistance measurements do not indicate the presence of moisture.

3-17. SYNCHROS AND SERVO SYSTEMS—GENERAL.

For the guidance of the technician whose assignments include the testing and servicing of synchros, a very brief description of the various types of synchros, and the various functions they perform, is given below.

a. TRANSMITTER (GENERATOR) SYNCHROS.—Transmitter synchros are used to transform an angular position of a shaft to an electrical signal voltage, the voltage being transformed to the identical shaft position by the receiver synchro connected to it. These synchros may be geared or not, depending upon the amount of accuracy required.

b. RECEIVER (MOTOR) SYNCHROS.—Receiver synchros are used in conjunction with the transmitter synchros. They receive the electrical signal voltage generated by the transmitter synchro and convert it to angular shaft position identical to the transmitter shaft position. These synchros may also be geared or not, depending upon the amount of accuracy required. To prevent overshooting and hunting, the receiver synchro rotor is provided with an inertia type damping device. For this reason, although a receiver synchro may be used for transmitting, a transmitting synchro may not be used for receiving.

c. DIFFERENTIAL SYNCHROS.—Differential synchros are used in conjunction with transmitter and receiver synchros. When used for transmitting, the differential synchro is used to insert a correction voltage in with the voltage from the transmitter synchro. In effect, the angular position of the transmitter synchro and the angular position of the differential synchro are compared, and the sum or the difference of these two positions is transmitted to a receiver synchro. Whether the sum or the difference voltage of the differential synchro is employed depends upon the method used to connect the transmitter, the differential, and the receiver synchros. A differential synchro which is used as a receiver indicates the angular difference or sum between two transmitter positions.

d. CONTROL TRANSFORMER SYNCHROS.—A synchro control transformer, known as a CT synchro, is similar to an ordinary synchro except that its rotor windings are used for generating a voltage known as an error voltage. Because this voltage is fed to the control grid of an electron-tube amplifier, the rotor windings are wound with many turns of fine wire, to produce a high impedance. Since the rotor is not fed an exciting voltage, the current drawn by the stator windings of the CT synchro would be fairly high if the windings were of the same type as in an ordinary synchro. To prevent this current from being excessive, the stator windings are wound with many turns of fine wire, to present a current-limiting impedance, and, in addition, a capacitor is connected across each of the three windings. The three synchro capacitors, manufactured in a single package, are shown schematically in figure 3-132.

e. SERVO SYSTEMS.—A servo system is a method of control by which a controlled quantity is compared with an ordered quantity, and the difference between the two quantities, known as the error voltage, is used to control the operation of the system. There are a great variety of servo systems in use, and it is not within the scope of this book to describe the systems in detail. There are electronic types, hydraulic types, amplidyne types,

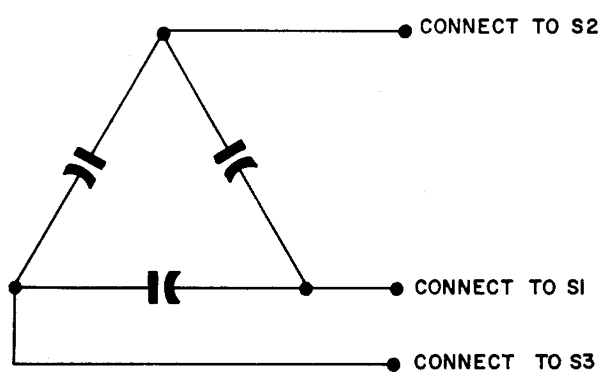


Figure 3-132. Synchro Capacitors and Connections

and many variations and combinations of these. All of these types of servo systems are designed for a specific task, and the applicable instruction book should be referred to for specific testing and detailed servicing instructions. All of the servo systems have anti-hunt features embodied in their design, in order to prevent oscillation. Electronic amplifiers used in servo systems are classified into the following four basic types:

Type 1. D-c input, d-c output
Type 2. D-c input, a-c output
Type 3. A-c input, a-c output
Type 4. A-c input, d-c output

Block diagrams illustrating these four basic types are shown in figure 3-133. For specialized uses, even these four basic types are varied to suit the particular application for which they may be needed.

3-18. SYNCHRO SYSTEM TESTING—GENERAL.

Since synchros are employed to transfer angular shaft position to another synchro, usually some distance away, long lengths of connecting bus and/or cable are used. Although the wiring may be clearly marked or color-coded, it is advisable to check these designations if a synchro system gives evidence of improper operation. This is important if a new installation is being checked, or if an installation has been repaired or overhauled.

a. OVERLOAD INDICATORS.—An overload in a synchro system is usually caused by worn bearings or defective gears at the receiver synchro. This condition causes the receiver rotor to lag the transmitter rotor, allowing excess current flow in the stator windings. To detect this condition, it is necessary to measure the current in at least two of the stator leads. This is necessary because synchro design makes it possible for one stator lead to indicate zero volts while the other two leads are drawing excessive current. The usual procedures and precautions should be followed when making these measurements. Some synchro systems may have an overload indicator included in the installation. This method utilizes two current transformers, the primary of each being connected in series with a stator lead. The secondary windings of these two transformers are connected in series-aiding, and the two remaining secondary leads are connected to a neon bulb. The secondary windings of these two transformers are so designed that the neon bulb fires when a predetermined unbalance in voltage in the two stator leads is present. The neon bulbs are usually mounted on the control switchboard of the equipment.

b. BLOWN-FUSE INDICATORS.—Some synchro systems may have a blown-fuse indicator included in the installation. This usually consists of a transformer with two primary windings and one secondary winding. The primary power is

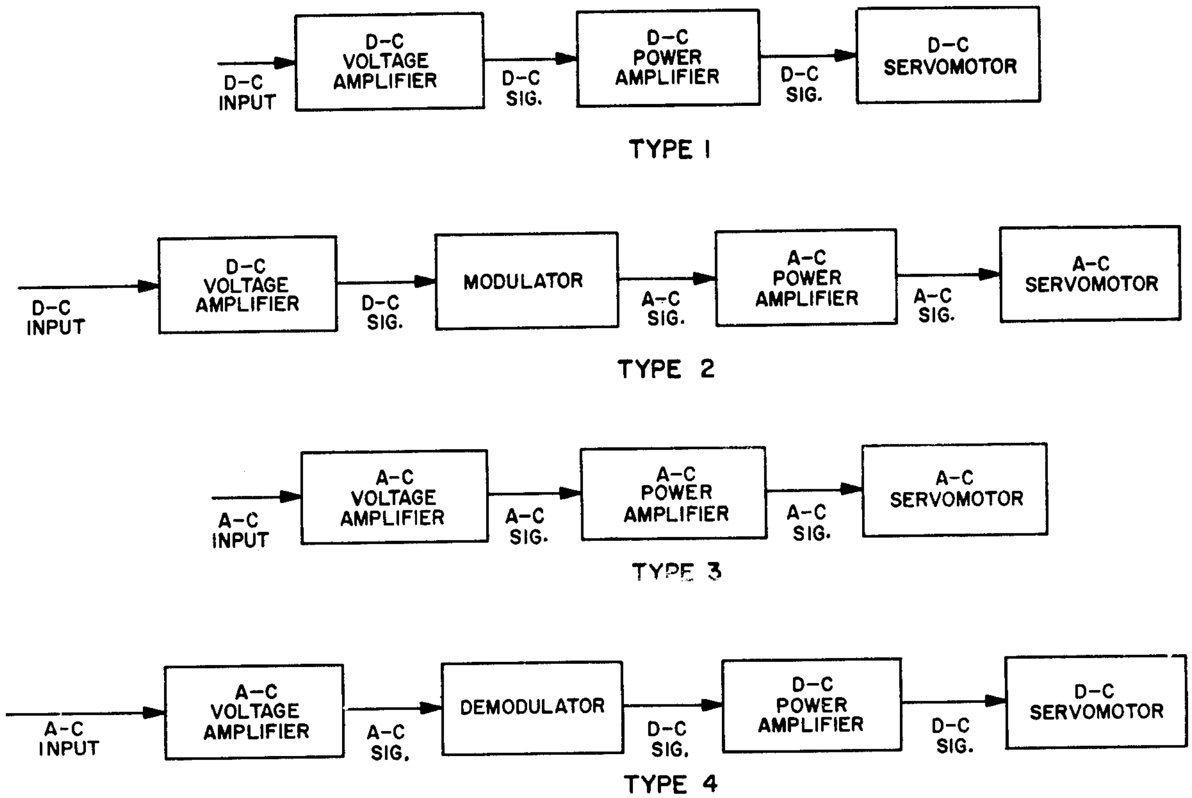


Figure 3-133. Four Basic Types of Servo Amplifiers (Electronic)

connected to one primary winding, and the synchro excitation voltage is taken from the other primary winding. The leads of one primary are jumpered by fuses to the leads of the other primary, the phasing being such that the voltages in the two windings oppose one another, so that normally no voltage is induced in the secondary. If one of the fuses blows, the primary winding connected to the primary power induces voltage in the secondary winding. This secondary winding is connected to a neon bulb, which glows, indicating a blown fuse.

c. VOLTAGE AND RESISTANCE MEASUREMENTS.—The quickest method of locating opens and shorts in synchro units and their associated wiring is by resistance measurements. Since most synchros work in pairs, it can be assumed that the resistances of both the rotors and the stators will show the same reading, within close tolerances. If the resistances should vary widely, the trouble may be easily located. Typical resistance values for synchros may run from a fraction of an ohm for the large synchros to a few hundred ohms for the smaller ones. Do not measure resistance without first shutting off all excitation voltage to the synchro rotors.

An excellent method for detecting open or shorted stator windings is to connect a voltmeter across any two of the stator windings. As the transmitted quantity is varied, a smooth variation between 0 and 90 degrees should be indicated by the voltmeter. Open or short-circuited stator or rotor leads may be detected by measuring with a voltmeter or by measuring the resistance of the suspected part.

d. SYMPTOMS AND CAUSES OF INCORRECT WIRING.—In new installations and after repairs or overhauls in synchro systems, crossing of buses or wires is frequently the cause of improper synchro operation. Reference to figure 3-134 should identify the cause of any improper operation of the synchro system.

e. SYNCHRO ZEROING METHODS.—In any synchro system it is most important to have all the synchros electrically zeroed. Since different types of synchros must be zeroed in a different manner, each type of synchro will be discussed.

(1) ZEROING RECEIVER SYNCHROS.—Since the receiver synchro is usually free to turn, the jumper method of zeroing is usually employed. To zero a receiver synchro, the voltage between S1 and S3 must be made zero, and the phase of the voltage at S2 should be the same as the phase at R1. This is easily done by connecting S1 and S3, using a jumper wire, and connecting S2 and S1, using a jumper wire. This method is shown in figure 3-135. When the power is applied, the rotor will line up in the zero position. If the indicator does not point to zero on the dial, loosen the syn-

chro in its mounting and rotate it until its dial reads zero.

(2) ZEROING TRANSMITTER SYNCHROS.—To zero a transmitter synchro, connect an a-c voltmeter between S1 and S3 as shown in part A of figure 3-136. Rotate the energized rotor until a zero reading is obtained on the voltmeter. Since rotor positions at zero degrees and 180 degrees will produce this zero reading, it will be necessary to determine whether the phase of S2 is the same as that of R1. Make the connections shown in part B of figure 3-136. If the proper polarity relationships exist, the voltmeter will indicate less than the line voltage being applied to the rotor. If the indication is greater than the line voltage, the rotor must be rotated 180 degrees and the previous step, as shown in part A of figure 3-136, performed again. The pointer connected to the rotor should be adjusted to indicate zero.

(3) ZEROING DIFFERENTIAL TRANSMITTER SYNCHROS.—Because the differential transmitter synchro is usually used to insert a correction voltage into a synchro system, it is normally driven either directly or through a gear train. Before zeroing the differential transmitter synchro, the unit whose position the differential synchro transmits should first be zeroed. After this has been done, connect the differential synchro as shown in part A of figure 3-137. Turn the synchro in its mounting until the voltmeter shows a minimum indication. After completing this step, make the connections shown in part B of figure 3-137. Again turn the synchro slightly in its mounting, until a minimum voltage is indicated by the voltmeter.

(4) ZEROING DIFFERENTIAL RECEIVER SYNCHROS.—To zero a differential receiver synchro, make the connections shown in figure 3-138. As soon as the power is applied to the synchro, the rotor will assume a position of electrical zero. The dial can then be set at zero and the unit reconnected to its circuit.

(5) ZEROING CONTROL TRANSFORMER SYNCHROS.—To zero a control transformer synchro, connect it as shown in part A of figure 3-139. Apply the power and turn the synchro in its mounting for a minimum reading on the voltmeter. Connect the control transformer synchro as shown in part B of figure 3-139, and again turn the synchro slightly in its mounting, in either direction, for a minimum indication on the voltmeter.

f. STANDARD TEST SYNCHROS.—A standard test synchro is used for performing various operational tests on synchro systems, and may be used for various kinds of checks and for trouble shooting. The standard test synchro is a small, precision synchro, mounted in an instrument case. It is equipped with a standard dial (numbers increasing in a clockwise direction) which moves past an engraved index. When the synchro is being used as a transmitter, a braking arrangement supplies friction to the shaft. When the synchro is being used for receiving, the brake is released to allow the shaft to turn freely.

3-19. SERVO (SERVOMECHANISM) SYSTEM TESTING—GENERAL.

a. ELECTRONIC CONTROL.—There are a great number of servo systems (servo-mechanisms) in which power is supplied to a driving motor from the output of a servo amplifier. Electronic control systems are generally employed where large amounts of torque are not required. Both d-c and a-c servomotors may be controlled directly from the output of electronic servo amplifiers.

(1) SYSTEM WITH D-C SERVOMOTOR.—A schematic layout of the elements constituting a simple positioning servo system is shown in figure 3-140. The d-c servomotor has a permanent-magnet field, a type which may be used when the load on the output shaft is not too heavy. In the system shown, the load is positioned without the use of electromechanical amplification, the electronic amplifier alone supplying sufficient power to cause motor armature rotation.

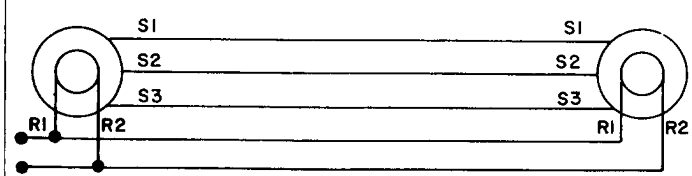
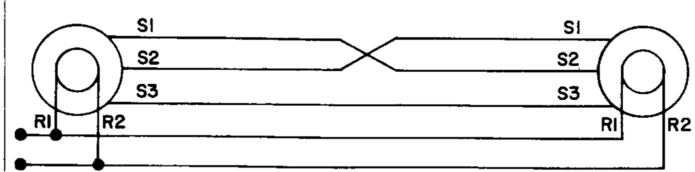
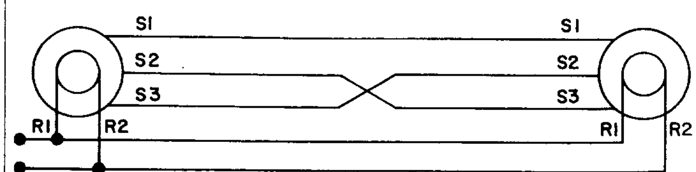
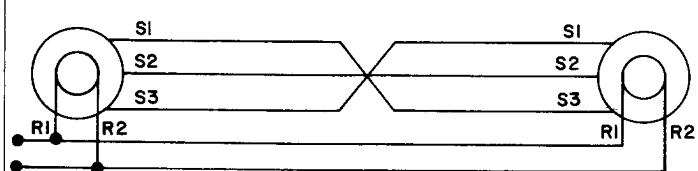
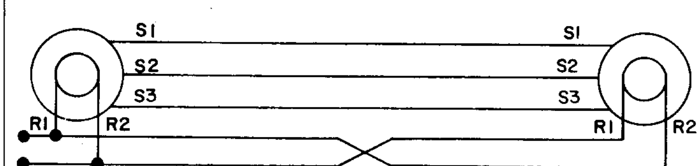
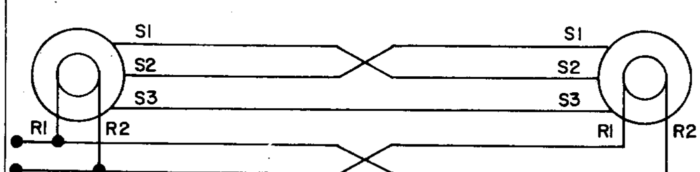
The servo amplifier in the positioning system consists of a phase-sensitive detector-amplifier, V1 and V2, coupled to a d-c amplifier, V3 and V4, by means of a cathode-loading arrangement. The error voltage from the CT (control transformer) rotor is coupled to the amplifier through transformer T1. It should be noted that the plate supply for V1 and V2 is an alternating voltage obtained from the secondary of transformer T2. The windings of T2 are connected so that the plate voltages of V1 and V2 are in phase, both voltages swinging positive or negative at the same time. In order that the grid and plate returns may be grounded, load resistors, R1 and R2, are placed in the cathode circuits rather than in the plate circuits. The grids of the a-c amplifiers are fed from the high sides of R1 and R2. Thus, each is supplied with a d-c voltage, filtered by shunt capacitors C1 and C2. The remainder of the d-c amplifier circuit is conventional, with the output of a rectified power supply applied to the junction of load resistors R7 and R8.

With no error voltage applied, both V1 and V2 conduct equally when point X is positive. As a result, both outputs Y and Z are at positive d-c potentials of equal magnitude. These outputs cause V3 and V4 to conduct the same amount and produce equal voltage drops across R7 and R8. Consequently, the output to the servomotor armature is zero. When point X swings negative, neither V1 nor V2 conducts, the grids of V3 and V4 are balanced by the equal potentials from C1

1

CHART A

FOR ALL WIRING TROUBLES SHOWN HERE, RECEIV
GIVES WRONG INDICATION OR TURNS IN A REVERSE
DIRECTION. TORQUE NORMAL. NO OVERLOAD. NO OVERHE

SPECIFIC SYMPTOMS		WIRING	TROUBLE	SPECIFIC SYMPTOM	
TRANSMITTER	RECEIVER			TRANSMITTER	RECE
SET ON 0° AND TURNED CCW	READS AND TURNS AS INDICATED			SET ON 0° AND TURNED CCW	READ TURN INDI
0°	0°		NO TROUBLE SYSTEM OPERATES NORMALLY	0°	3
0°	240°		S1 AND S2 REVERSED	0°	18
0°	120°		S2 AND S3 REVERSED	0°	12
0°	0°		S1 AND S3 REVERSED	0°	2
0°	180°		R1 AND R2 REVERSED	0°	30
0°	60°		R1 AND R2 REVERSED S1 AND S2 REVERSED	0°	6

Fi

A

SHOWN HERE, RECEIVER
TURNS IN A REVERSE
OVERLOAD. NO OVERHEATING.

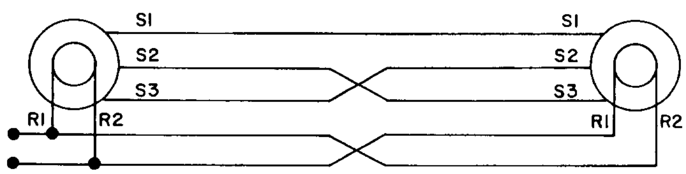
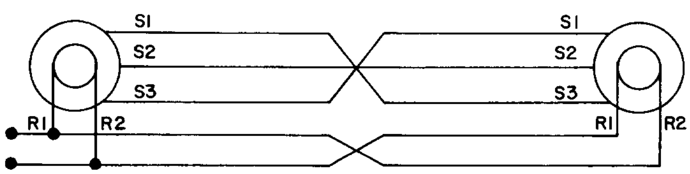
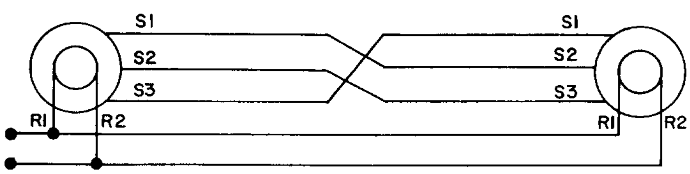
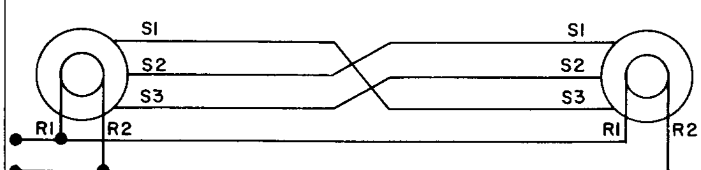
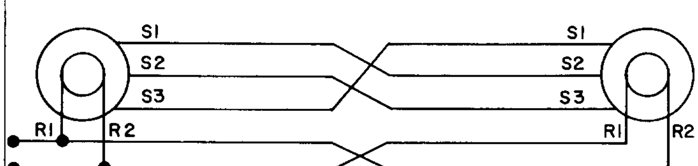
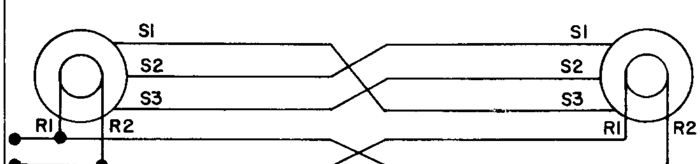
SPECIFIC SYMPTOMS		WIRING	TROUBLE
RANSMITTER	RECEIVER		
SET ON 0° AND TURNED CCW	READS AND TURNS AS INDICATED		
0°	300°	 	R1 AND R2 REVERSED S2 AND S3 REVERSED
0°	180°	 	R1 AND R2 REVERSED S1 AND S3 REVERSED
0°	120°	 	S1 TO S2 S2 TO S3 S3 TO S1
0°	240°	 	S1 TO S3 S2 TO S1 S3 TO S2
0°	300°	 	R1 AND R2 REVERSED S1 TO S2 S2 TO S1 S3 TO S1
0°	60°	 	R1 AND R2 REVERSED S1 TO S3 S2 TO S1 S3 TO S2

Figure 3-134. Symptoms and Causes of Incorrect Wiring

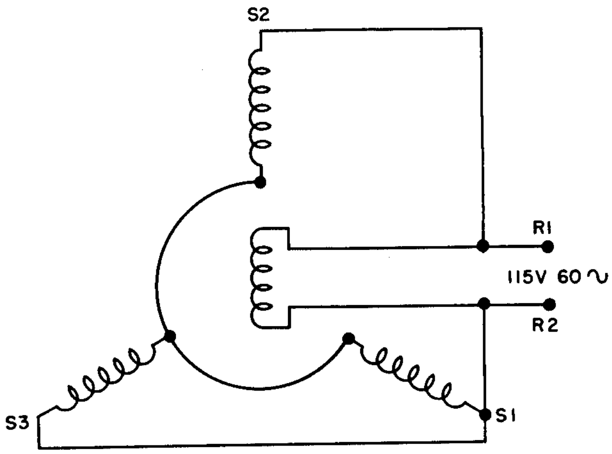


Figure 3-135. Method Used for Electrically Zeroing a Receiver Synchro

and C2, and the output voltage to the servomotor armature remains at zero. When an error voltage is present, so that the grid of V1 is positive at the same time as point X, plate current through V1 increases, while that through V2 decreases. Since point Y is now more positive than point Z, V3 conducts more heavily than V4, effecting an unbalance in the voltage drops across R7 and R8. This means that the output to the servomotor is negative at A with respect to B. When the error voltage is reversed in phase (180 degrees difference), V2 and V4 become the heavier conducting tubes, causing the polarity at A with respect to B to reverse from the previous condition. The phase relationship between the error and reference voltages determines the direction of servomotor rotation. The speed of motor rotation depends upon the magnitude of the error voltage. The output shaft is geared to the CT rotor, which turns in the proper direction to reduce the error voltage to zero. The position of the load is reported to the command position by the synchro indicator system at the left-hand side of the diagram.

In cases where the load to be positioned is very light, a small, low-power servomotor may have its armature connected directly to points Y and Z, thus eliminating the d-c amplifier, V3 and V4.

(2) SYSTEM WITH A-C SERVOMOTOR.—One method for controlling an a-c servomotor by electronic means is shown in figure 3-141. The circuit shown is used in certain radar systems in which an a-c servomotor is geared to the deflection coil of a PPI scope. The synchro systems used with this servomechanism may be duplicates of those shown in the d-c example of figure 3-140, and are therefore not included in the diagram.

The error voltage is taken from the rotor of the synchro control transformer and fed to a conventional R-C coupled a-c amplifier. R1, R3, C1, and C2 are components of an error-rate damping network, the operation of which is discussed in a later section of the manual. The uncontrolled phase winding of the a-c servomotor is connected to the 115-volt, 60-cycle source, which also serves as the reference voltage. Capacitor C6 is used to provide a 90-degree phase shift (necessary for two-phase motor operation) between the motor winding and the reference voltage. A portion of the output voltage is applied as degenerative feedback to the cathode circuit of V2, with the amount of feedback controlled by the servo gain potentiometer.

With zero error voltage, the controlled phase of the servomotor is not energized and there is no load rotation. When an error signal is present, the amplified signal, which appears across the secondary of the output transformer, will be either in phase, or 180 degrees out of phase, with the

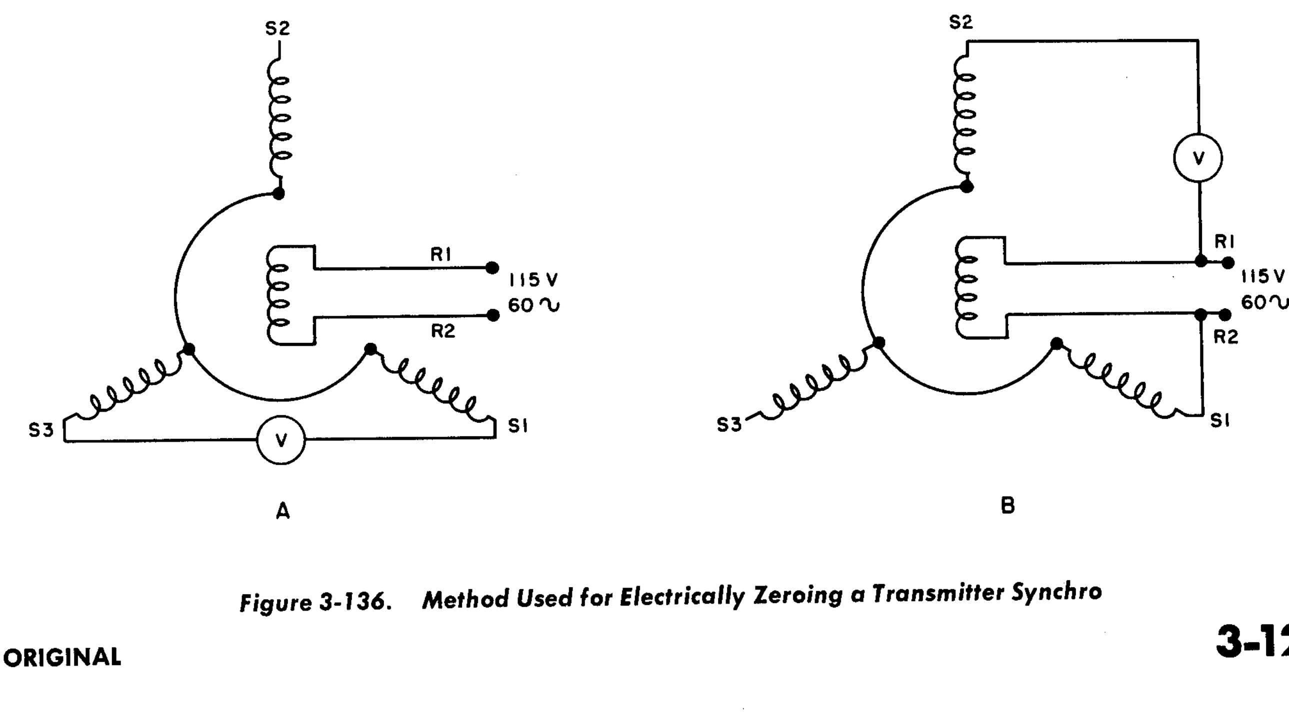


Figure 3-136. Method Used for Electrically Zeroing a Transmitter Synchro

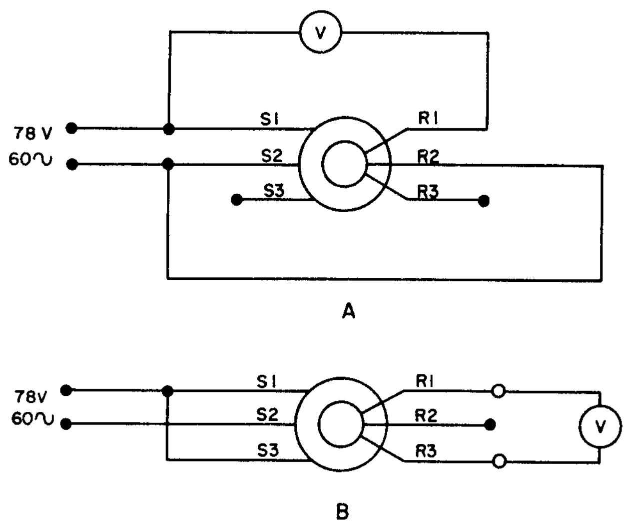


Figure 3-137. Method Used for Electrically Zeroing a Differential Synchro (Transmitter)

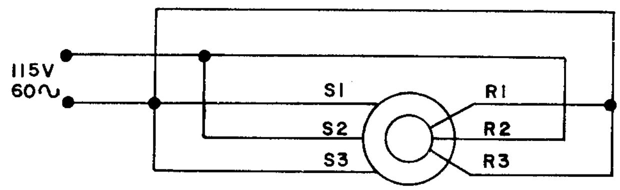


Figure 3-138. Method Used for Electrically Zeroing a Differential Synchro (Receiving)

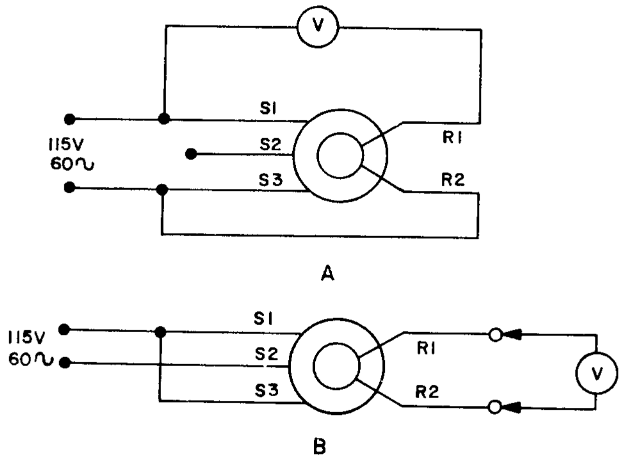


Figure 3-139. Method Used for Electrically Zeroing a Control Transformer Synchro

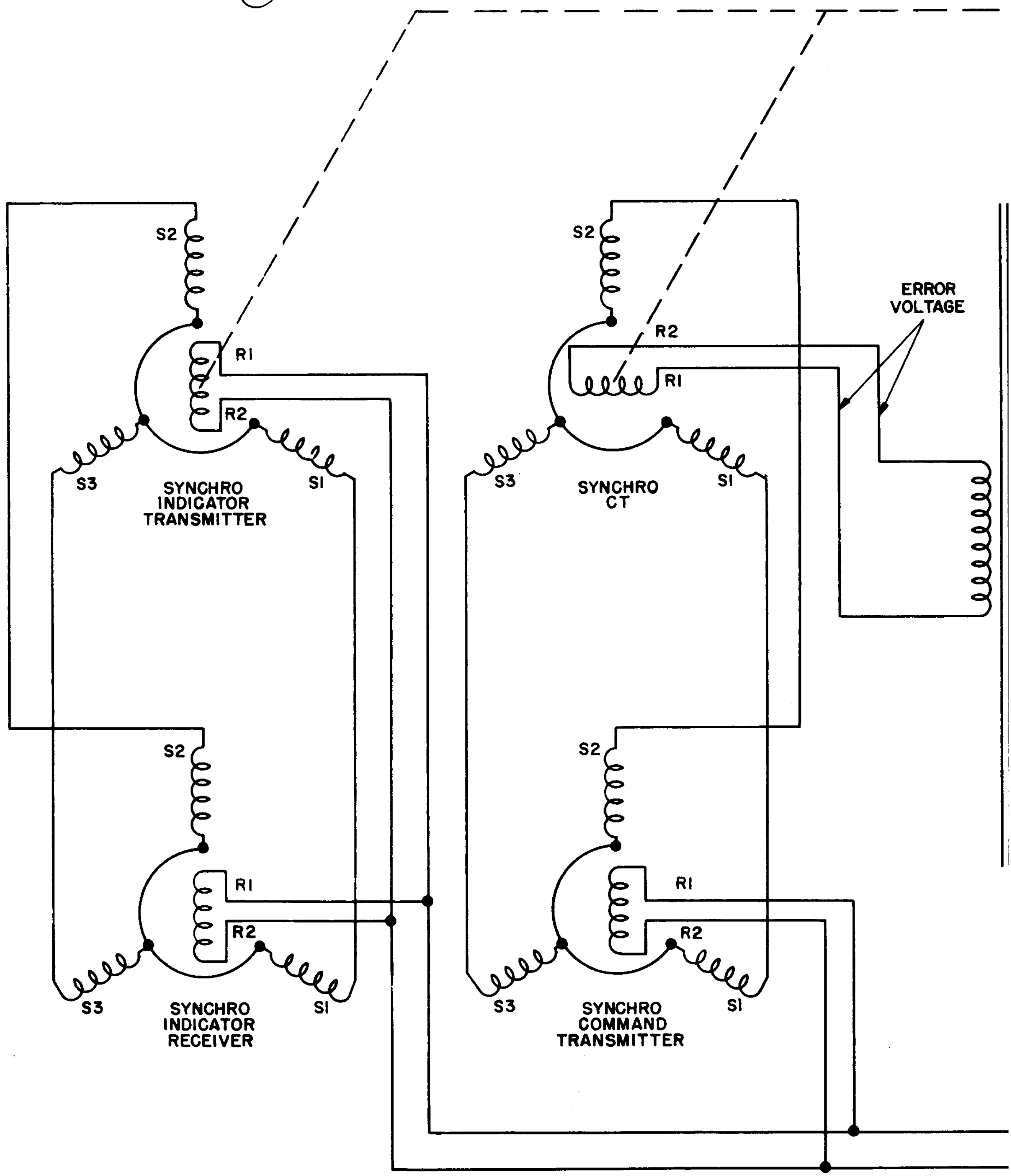
reference voltage. Thus, the direction of servomotor rotation depends upon the phase relationship existing between the error and reference voltages. As in other systems discussed, the servomotor shaft, which is geared to the load, is also geared to the CT rotor, providing rotation in the proper direction to reduce the error.

(3) THYRATRON CONTROL.—In considering armature current control methods for servomotor operation, an amplifier using vacuum tubes is found to be satisfactory for lightly loaded systems. However, when load requirements increase, calling for more powerful servomotors and accompanying larger load currents, vacuum-tube control becomes inefficient. This is because the vacuum tube has an inherently high plate resistance which imposes serious limitations in cases of high current demands. Of course, where current demands are heavier, larger vacuum tubes could be employed, necessitating higher operating voltages. However, the additional expense, and the increased size and weight of such amplifier units are disadvantages which cannot be ignored. One solution to this problem lies in the use of the thyratron tube.

The thyratron is a gas-filled, grid-controlled tube, capable of handling much greater load currents than a vacuum tube of equivalent size. It differs from the vacuum tube in three important respects. First, its plate-to-cathode resistance is so low in the conducting state that the voltage drop across the tube rarely exceeds 15 volts for full-rated current. Second, while the grid of the thyratron controls the point at which the thyratron fires, or ionizes, once ionization takes place, the grid loses all control and cannot stop plate-current flow. As a result of this thyratron characteristic, the tube can be extinguished only by lowering the plate voltage to the deionizing level. Third, the thyratron passes either full circuit current or no current. Therefore, while both types of tubes act as rectifiers, the vacuum tube may be regarded as a rheostat in series with the load, whereas the thyratron action is that of an on-off switch. Since it is not desirable for a servomotor to jump from no-speed to full-speed, circuits are devised whereby the average current flow is controlled by shifting the firing point of the tube.

(*a*) CRITICAL GRID BIAS CURVE.—By varying the bias on the grid of the tube, the point at which the thyratron "switch" closes may be controlled. That is, the grid bias determines the value of plate-to-cathode voltage at which ionization takes place. For any value of plate voltage, there is a maximum negative grid potential, called the critical grid bias, below which the thyratron cannot fire. For a constant d-c plate voltage, there is a constant critical grid bias. For an a-c plate voltage, varying sinusoidally from zero to peak voltage values, the critical grid bias varies in inverse proportion, as illustrated in figure 3-142. Part A of the diagram shows that firing occurs at the point where the applied grid bias voltage level intersects the critical grid bias curve. If the grid bias voltage level is made more negative than the peak of the critical grid bias curve (part B), they do not intersect and the thyratron cannot fire.

1


S2
R1
R2
S3
S1
SYNCHRO
INDICATOR
TRANSMITTER
S2
R2
R1
S3
S1
SYNCHRO
CT
ERROR
VOLTAGE
S2
R1
R2
S3
S1
SYNCHRO
INDICATOR
RECEIVER
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SYNCHRO
COMMAND
TRANSMITTER

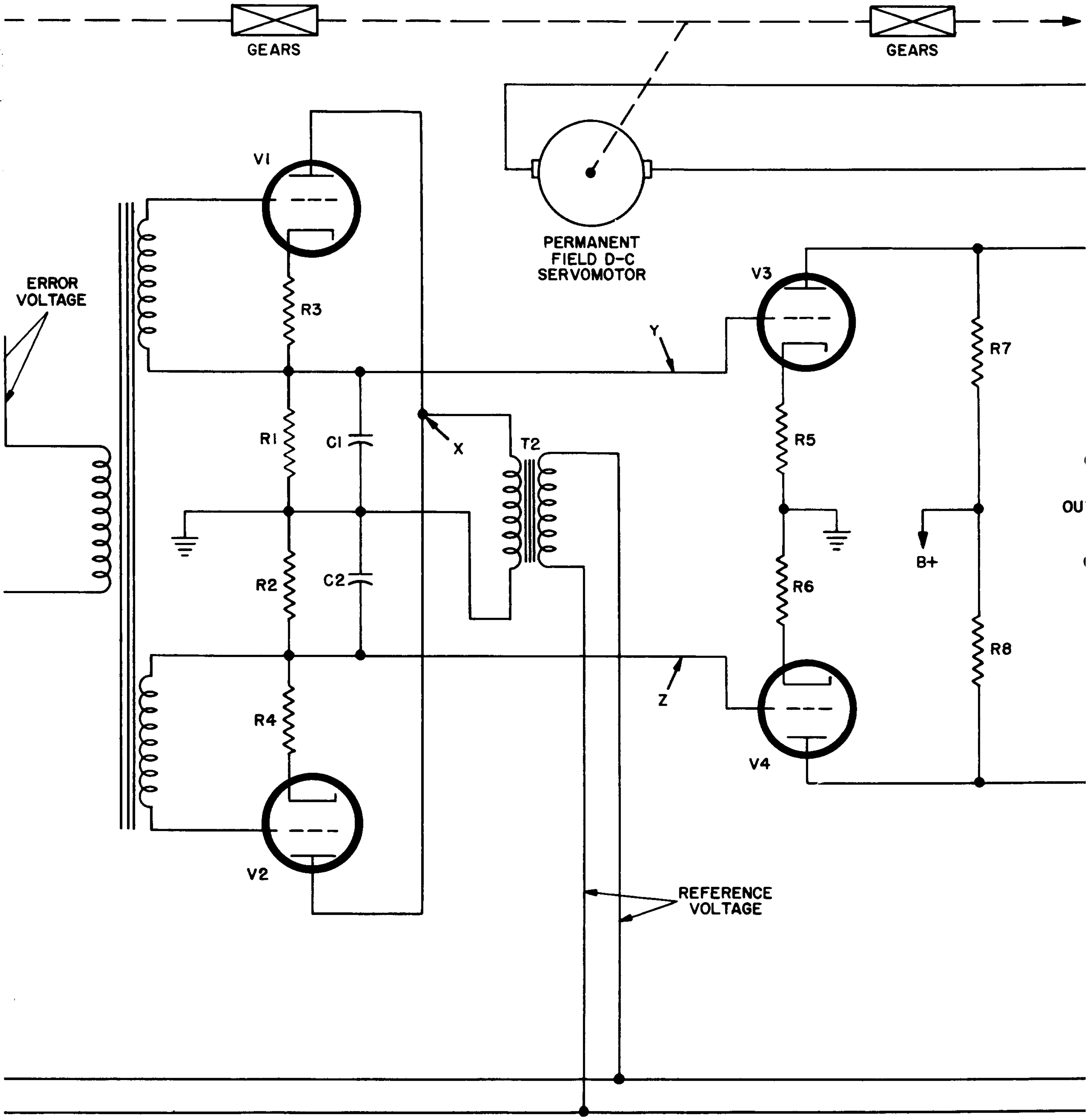
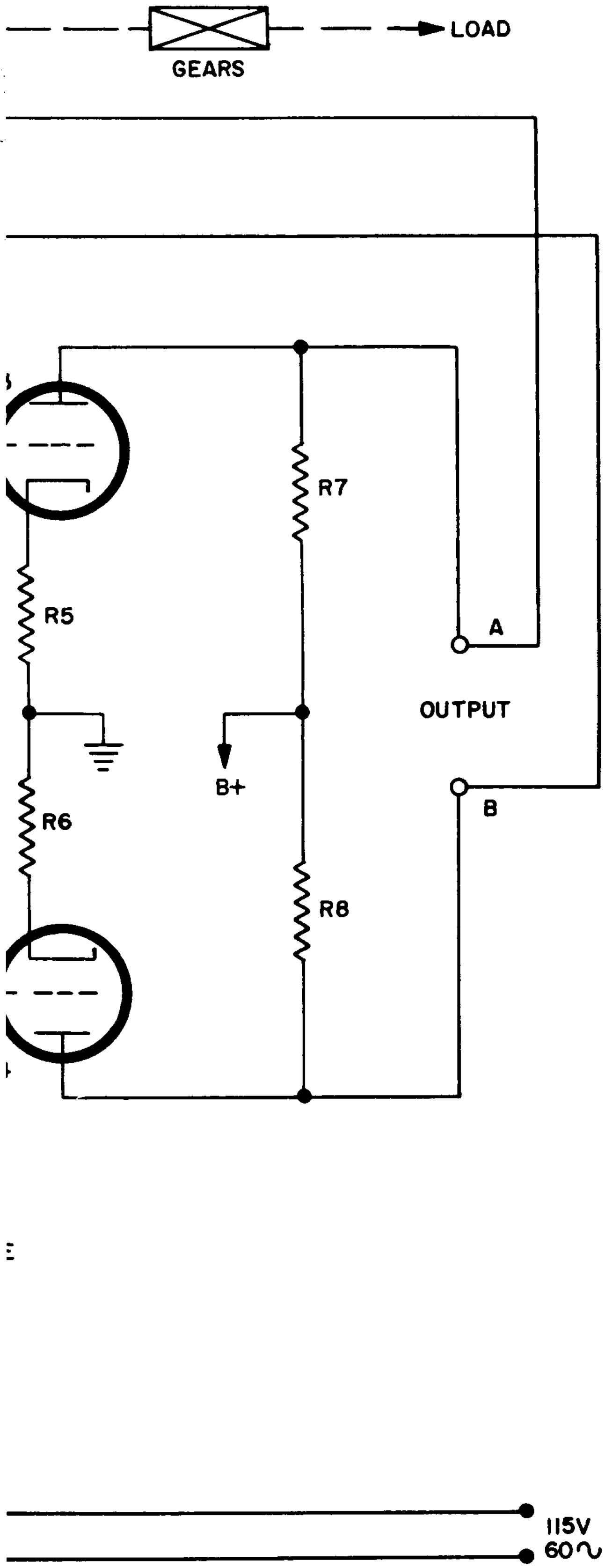


Figure 3-140. Servomechanism Showing Electronic Control of D-C Servomotor



Electronic Control of D-C Servomotor

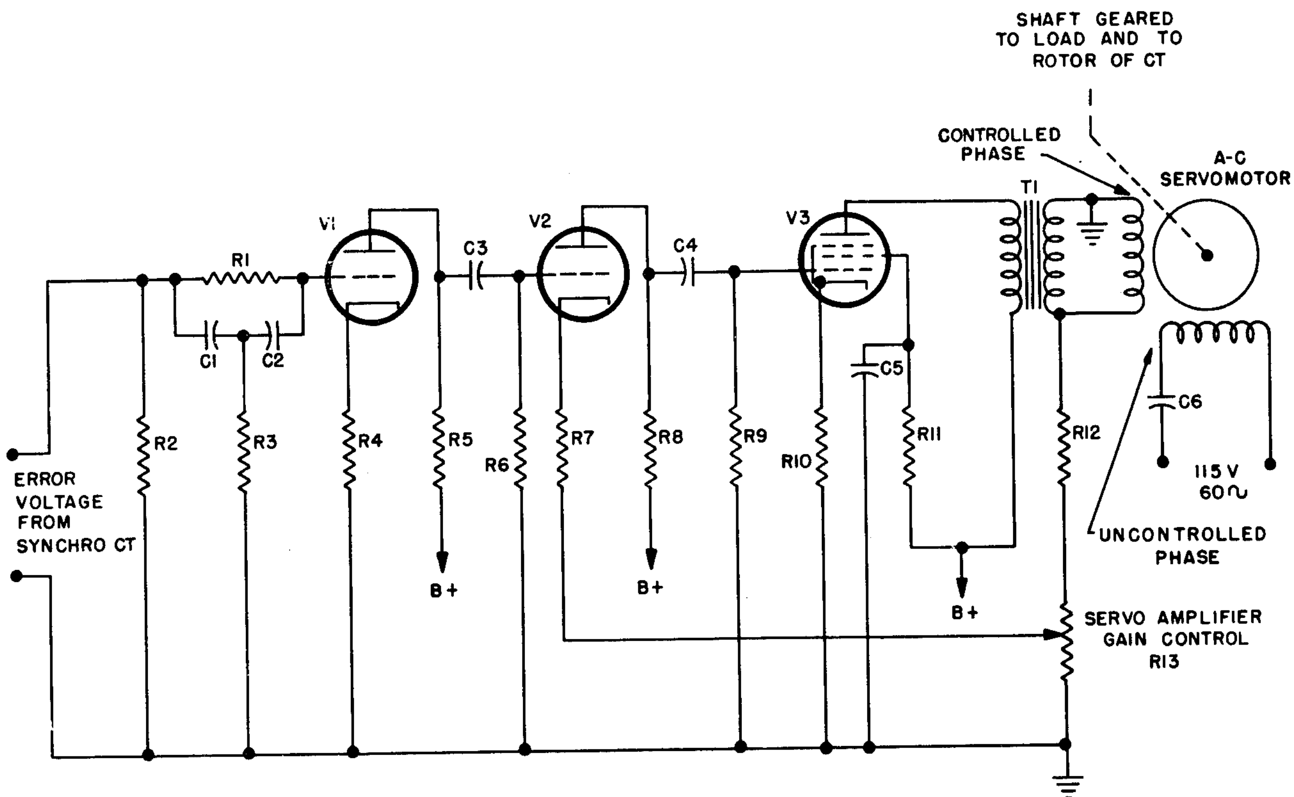


Figure 3-141. Servomechanism Showing Electronic Control of A-C Servomotor

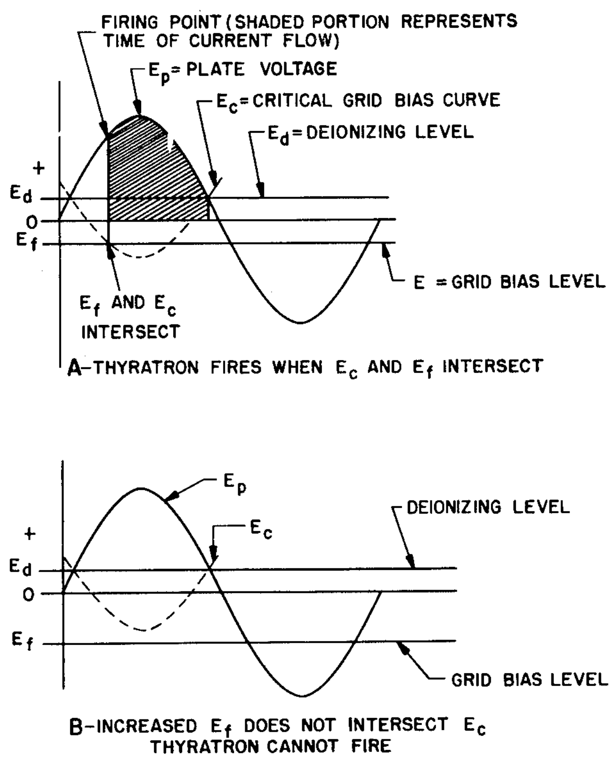


Figure 3-142. Grid Bias Thyratron Control

When an a-c signal, in phase with, and of the same frequency as, the plate-supply voltage, is superimposed upon the d-c grid-bias level, the thyratron may be made to conduct during different portions of the positive half-cycle. Thus, in figure 3-143, it is seen that the firing point may be delayed by varying the amplitude of the a-c grid signal. Examination of the curves makes it apparent that this amplitude control method cannot delay the firing point of the tube beyond 90 degrees. Within the 90-degree limit, varying the grid voltage allows the thyratron to control the speed of the servomotor, in addition to its rectifying and switching functions.

(*b*) THYRATRON SERVO AMPLIFIER FOR D-C SERVOMOTOR CONTROL.—A circuit for a thyratron servo amplifier, using the amplitude method of control, is illustrated in part A of figure 3-144. Unlike most input transformers, the secondary windings of T1 are connected so that the grid voltages of V1 and V2 are in phase. The two secondaries of T2, on the other hand, are arranged so that the plate voltages of V1 and V2 are out of phase, as indicated by the instantaneous polarities marked on the diagram. Part B of the figure shows the plate-voltage curves for V1 and V2 with the corresponding critical grid bias curves and d-c grid-bias levels. In the example shown, the error voltage is zero, and the curves indicate that values of grid-bias voltage have been chosen

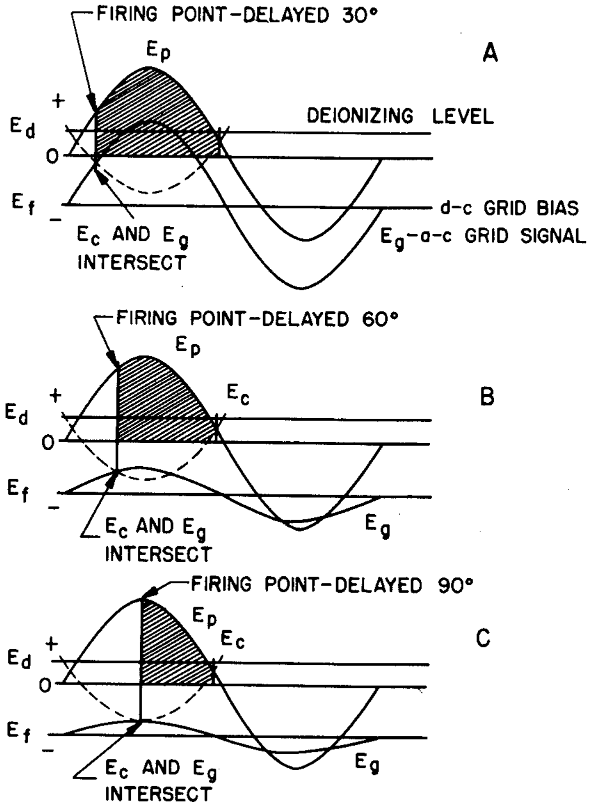


Figure 3-143. Thyratron Firing Point Controlled by Amplitude of In-Phase Grid Signal

so that E_f does not intersect the critical grid bias curves. Consequently, neither tube can fire and no current is supplied to the armature of the servomotor.

Figure 3-145 shows the amplifier action when an error signal is present. In this instance, E_{g1} is in phase with E_{p1} and intersects the V1 critical grid bias curve as indicated. V1 therefore conducts during a portion of each positive alternation of E_{p1}. When the V2 plate voltage swings positive, E_{g2} is negative-going and does not intersect E_{c2}. Thus, V2 cannot conduct. Current flows from Y to X through the servomotor armature, causing rotation in one direction.

If the error voltage from the control transformer shifts 180 degrees, so that it is in phase with E_{p2} (figure 3-146), V2 conducts and V1 becomes the non-conducting thyratron. Current now flows from X to Y through the armature, and the servomotor rotation is in the opposite direction.

(*c*) PHASE-SHIFT CONTROL.—It has been noted in the previous discussion that amplitude control of the thyratron firing point is limited to a 90-degree delay. It is obvious that, if by some means the time of firing is extended beyond the 90-degree point, a more proportional control will be realized, resulting in an improved servomotor response. A method whereby the firing point may be varied over almost a 180-degree

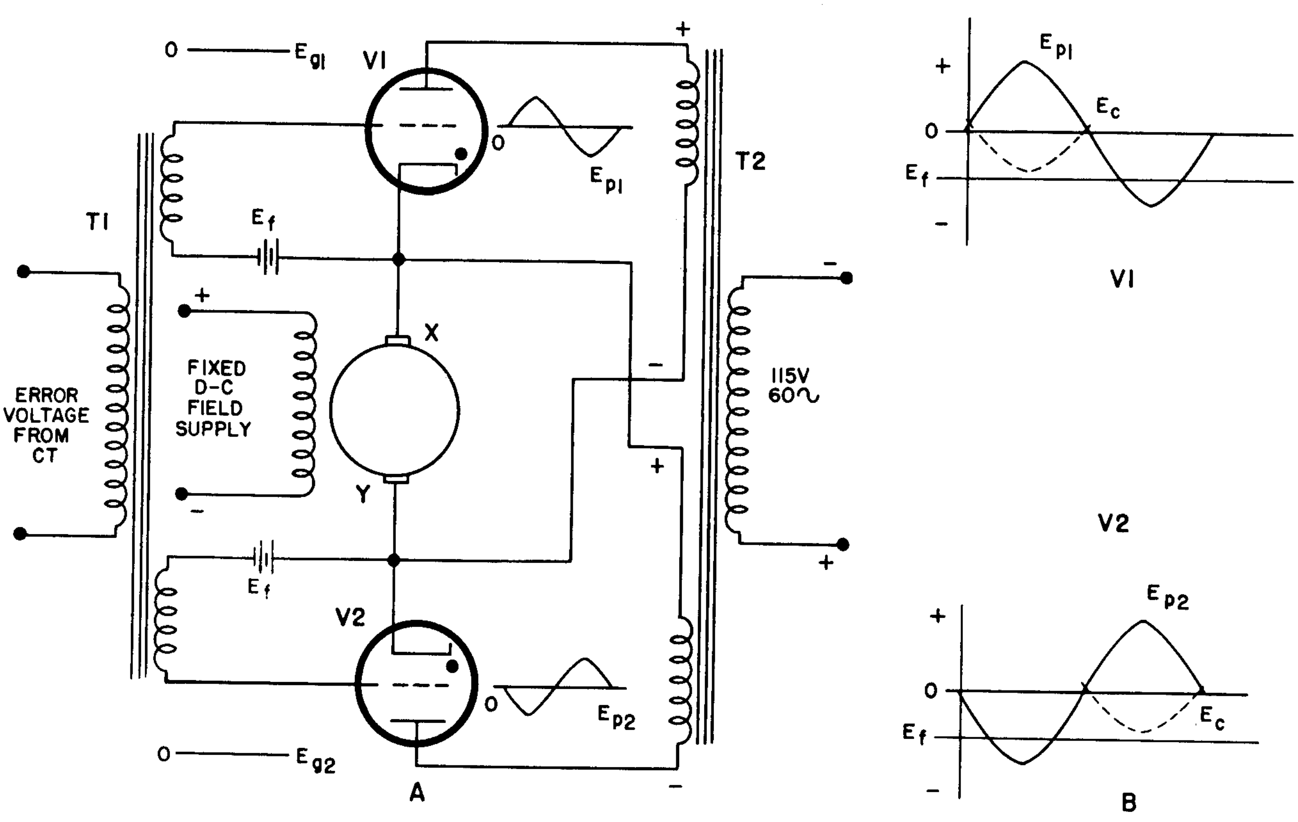


Figure 3-144. Thyratron Motor Control System with Zero Error Signal

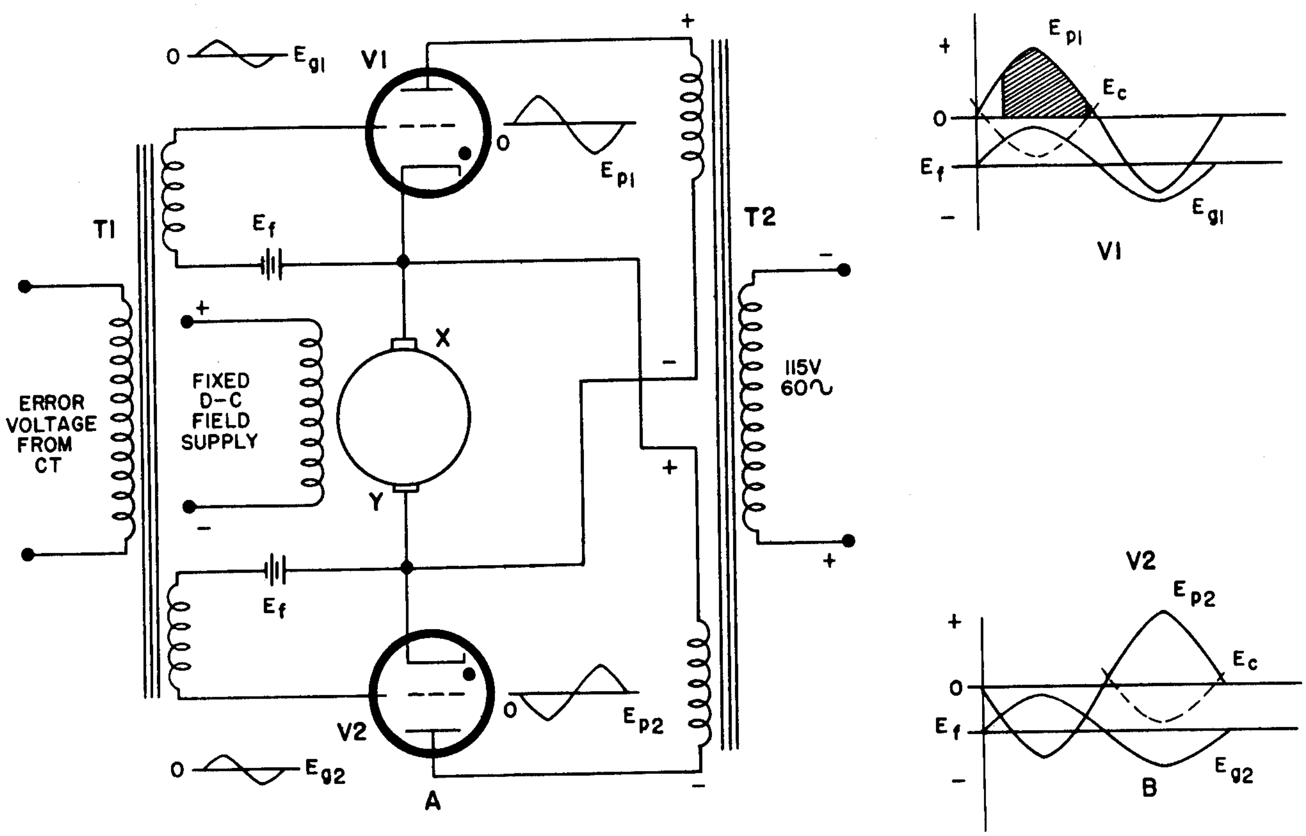


Figure 3-145. ***Thyratron Motor Control System with Error Signal in Phase with*** E_{p1}

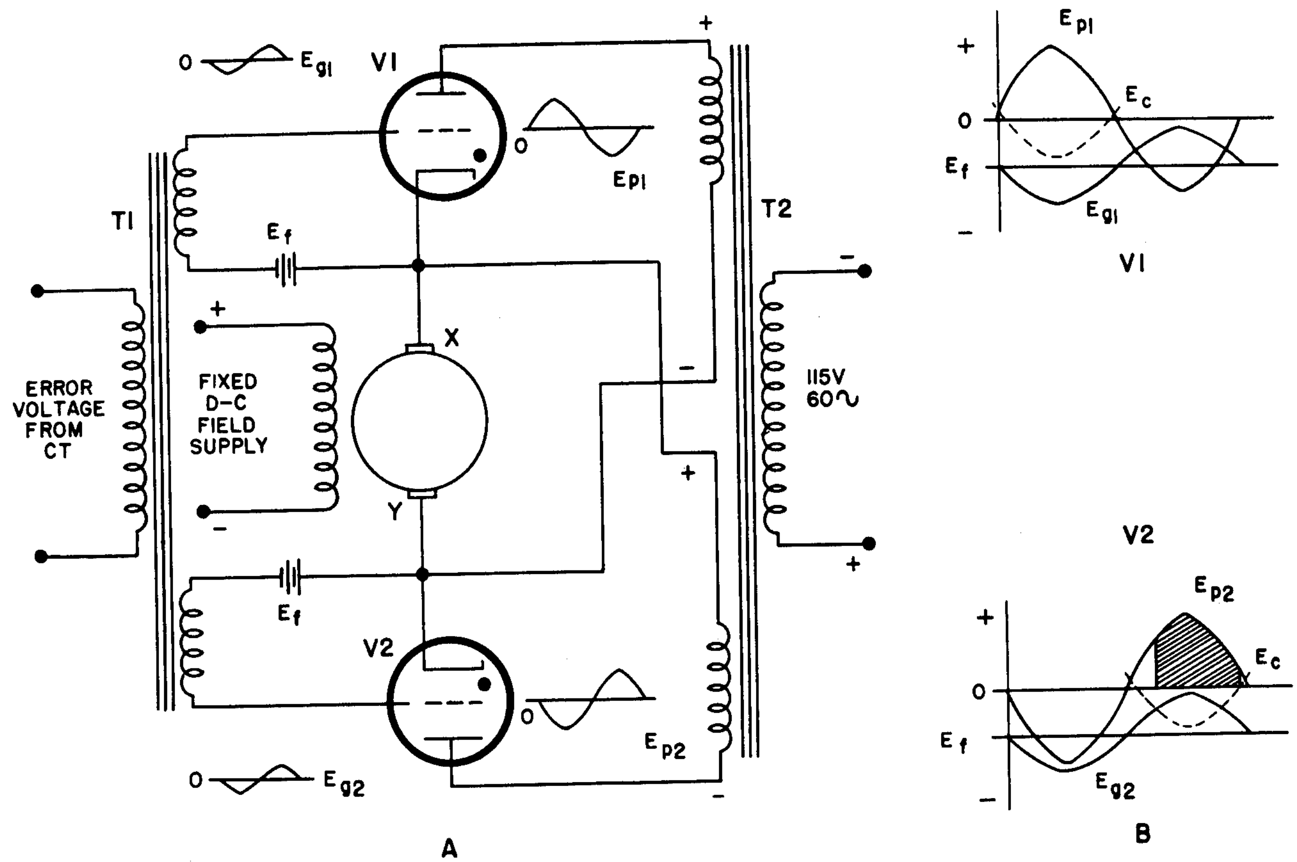


Figure 3-146. ***Thyratron Motor Control System with Error Signal in Phase with*** E_{p2}

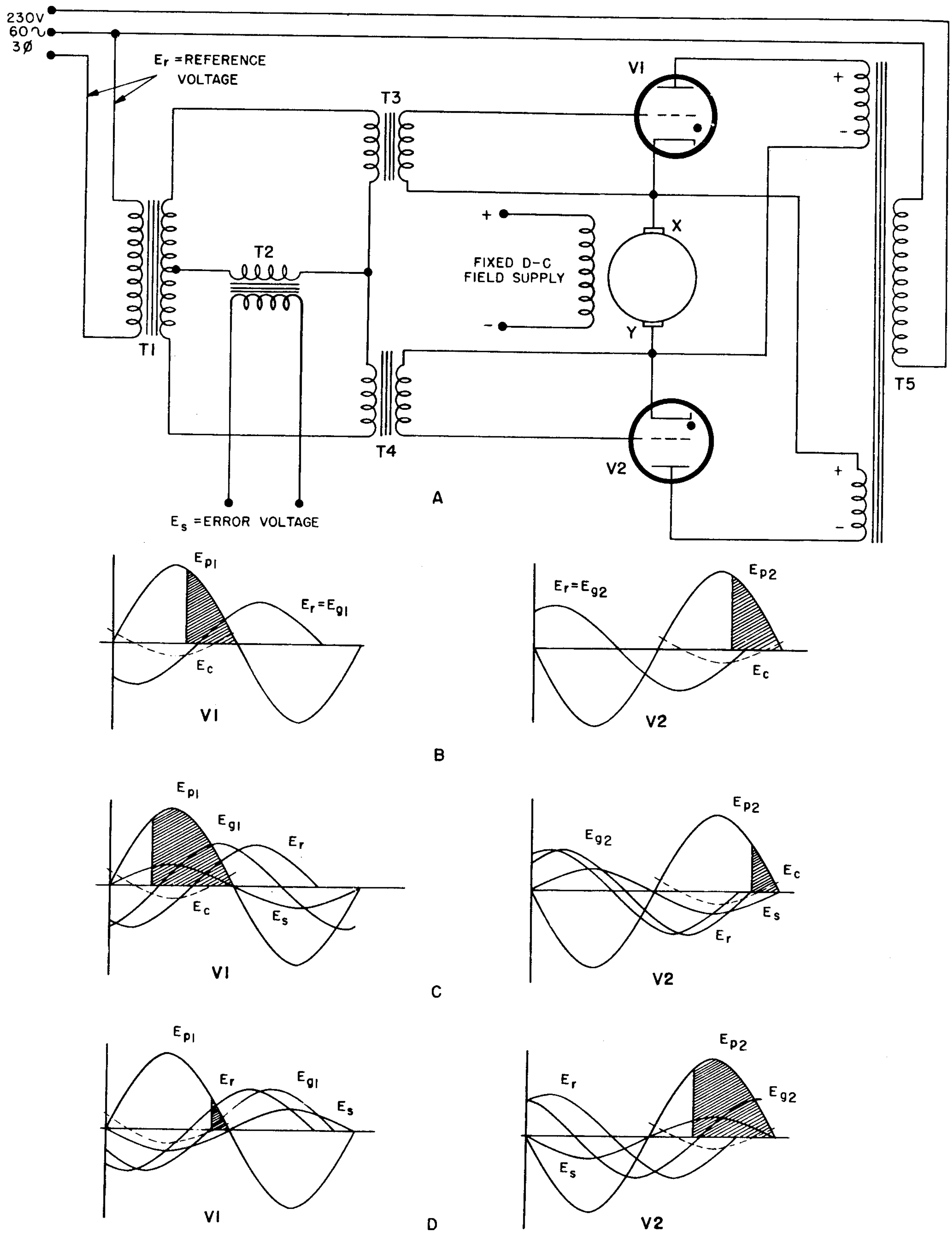


Figure 3-147. Thyratron Phase-Shift Motor Control System

range is known as phase-shift control. This method consists of adding a third, or reference, voltage to the two voltages shown in the earlier examples. In the circuit of figure 3-147, the primaries of reference transformer T1 and plate-supply transformer T5 are connected to a three-phase power source, so that the two voltages are 120 degrees out of phase. Control of the thyratron firing point is accomplished by combining the reference voltage with the error voltage which is fed into transformer T2. The phase-shift amplifier illustrated is set up so that the following phase conditions exist: (1) the voltages at the plates of V1 and V2 are out of phase; (2) the voltages at the grids of V1 and V2 are in phase with the error voltage; and (3) the voltages at the grids of V1 and V2 are out of phase with the reference voltage. For explanation purposes, it is assumed for the first condition that the error voltage E_s is zero. Therefore, since there is no E_s component, E_g in this case must be E_r, which is known to be 120 degrees out of phase with E_p. The curves for this condition, part B, show that both V1 and V2 conduct equally during their respective positive plate alternations. Thus, equal and opposing current pulses are applied to the armature, and there is no rotation.

In the next example, an error voltage E_s, in phase with E_{p1}, is introduced. Part C of the diagram shows that for V1, the out-of-phase summation of E_s and E_r acts to decrease the phase lag of the effective grid voltage E_{g1}, causing V1 to fire early in the positive alternation of E_{p1}. Conversely, the in-phase summation of E_s and E_r for the V2 thyratron shows that the phase lag of grid signal E_{g2} is increased so that V2 fires very late in its conducting half-cycle. Thus, the heavier V1 current takes control, flowing through the armature from Y to X.

When the error-voltage phase is shifted 180 degrees, so that it is in phase with E_{p2}, the conditions in part D prevail, causing the servomotor to reverse its direction of rotation.

For the phase-shift type of operation, it can be seen that the amount of phase shift obtained is dependent upon the magnitude of the error signal E_s. The greater the E_s magnitude, the greater the inequality in the V1 and V2 average currents. As the error voltage falls toward zero, the thyratron currents approach the balanced condition for which the servomotor comes to rest.

(*d*) ANTI-HUNT CIRCUIT.—The basic circuit of figure 3-144 may be modified to include an anti-hunt circuit, as shown in figure 3-148. In the no-error condition, the fixed grid bias is adjusted by means of R3 so that V1 and V2 cannot fire. When an error voltage appears which bears a phase relationship to the reference voltage as indicated by the symbols, V1 conducts. Current flows through the d-c motor armature in the direction indicated by the arrows, causing armature rotation. In the rotating state, the armature tends to act as a generator, and develops a counter electromotive force with a polarity as indicated. Thus, the current produced by the counter emf opposes the applied current. Since the series combination of R1 and R2 is across the armature, the voltage

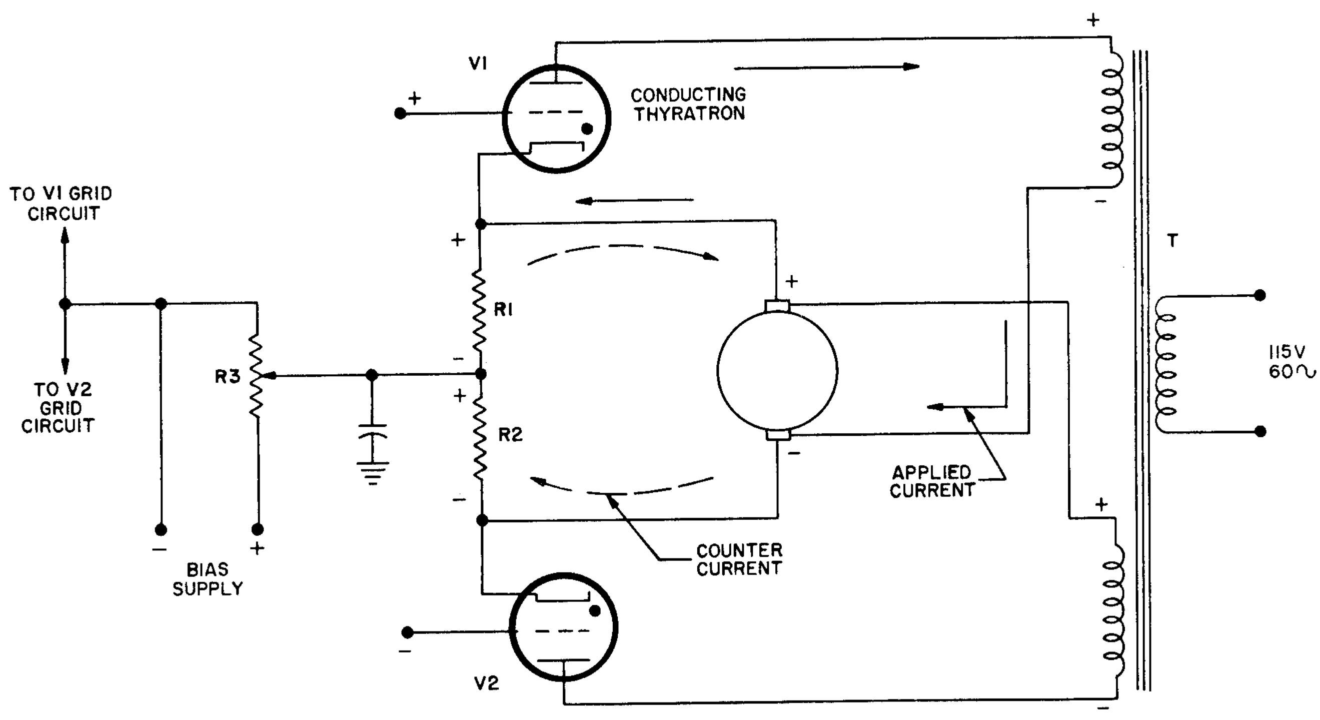


Figure 3-148. Use of Counter E.M.F. for Anti-Hunt Device

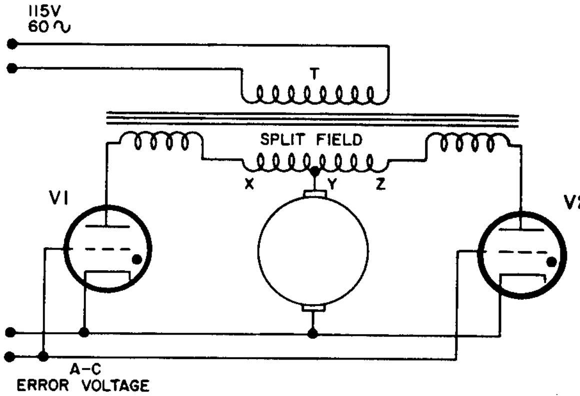


Figure 3-149. Thyratron Amplitude Control of Split-Field D-C Servomotor

across R1 tends to increase the negative bias on V1, thus providing for degenerative feedback. This action tends to stabilize the armature current to a substantially constant value. As the error voltage decreases, V1, being biased by the fixed supply plus the drop across R1, is cut off just before the load reaches the ordered position. At this instant, V2, which is biased by the fixed supply minus the drop across R2, conducts momentarily. The reversed current to the armature acts as a brake, which quickly checks the load motion. Thus, by means of proper circuit constants and accurate adjustment, the device functions to eliminate overshoot and hunting.

(*e*) THYRATRON CONTROL OF SPLIT-FIELD D-C SERVOMOTOR.—For servo systems using the split-field type of d-c servomotors, a thyratron arrangement similar to that of figure 3-149 may be used. In the simple circuit shown, the voltages at the grids of V1 and V2 are in phase with the error voltage, while the voltages at the plates of the tubes are out of phase with the reference voltage. With no error voltage, V1 and V2 conduct alternately and equally on their positive half-cycles, sending current pulses first from X to Y, then from Z to Y, through the split field and armature windings of the servomotor. The net current is zero, and there is no rotation. For an error voltage in phase with E_{p1}, V1 conducts heavily when plate and grid are positive. On the following alternation, when the V2 plate voltage swings positive, its grid signal swings negative. Thus, V2 either does not conduct at all (large error voltage), or conducts a small amount (small error voltage). Current flow for this condition is seen to be from X to Y. When the error voltage reverses, so as to be in phase with E_{p2}, the opposite set of conditions is established.

(*f*) THYRATRON SERVO AMPLIFIER FOR A-C SERVOMOTOR CONTROL.—There are several circuit variations in which the thyratron is used to control the operation of an a-c servomotor. A representative servo amplifier for this purpose is diagrammed in figure 3-150. T3 acts as the plate-supply and reference-voltage transformer, with secondary windings arranged so that the voltages at the V1-V4 plates are in phase, as are the voltages at the V2-V3 plates. The error voltage is applied to input transformer T1. T2 is the output transformer to the controlled-phase winding of the servomotor. If no error signal is present, none of the thyratrons fires, because the negative d-c grid-bias level is such that it does not intersect the critical grid bias curve. If an error voltage appears, with an instantaneous positive polarity at the top of the T1 secondary at the same time the V1 plate swings positive, V1 fires. V2 cannot fire because its plate is negative, and V4, having an additional negative bias, remains cut off. As long as the error voltage maintains this phase relationship, V2 and V4 cannot fire. On the first alternation, then, current flows from X to Y through the output transformer. On the following alternation, both grid and plate of V3 swing positive, and V3 fires, with a plate-current flow from Z to Y in T2. Thus, V1 and V3 conduct on alternate half-cycles, causing an a-c voltage to be induced into the T2 secondary. This voltage may be either in phase with the reference voltage or out of phase. The servomotor now turns in the ordered direction. Reversal of the error voltage phase causes V2 and V4 to become the conducting thyratrons and shifts the controlled phase 180 degrees with respect to the reference voltage. Hence, the servomotor reverses its direction of rotation.

(*g*) THYRATRON-SATURABLE REACTOR CONTROL.—Another circuit for the control of a-c servomotors is illustrated in figure 3-151. Two thyratrons are used here in conjunction with a pair of saturable reactors. The phasing requirements in this example are such that the V1-V2 grids are in phase with the error signal, while their plates are out of phase with the plate-supply voltage. One side of the servomotor control field is connected to the center-tap (B) of the T3 secondary. The other terminal connects to both ends of the T3 secondary through the two saturable reactor secondary windings, X1 and X2, as shown. In the no-error condition, V1 and V2 conduct equally on their alternate positive half-cycles and the reactors are balanced. Thus, points B and D are at the same potential, and the servomotor control field is not energized. When an error voltage is introduced which is positive when the V1 plate is positive, V1 conducts heavily and V2 does not conduct at all, because its plate is negative. Consequently, reactor X1 is saturated by the d-c output of V1, reducing the inductance of the X1 secondary winding to a low value. Effectively, therefore, point D is connected to point A through a low reactance, and the motor control field is energized in one direction. When the error signal from T1

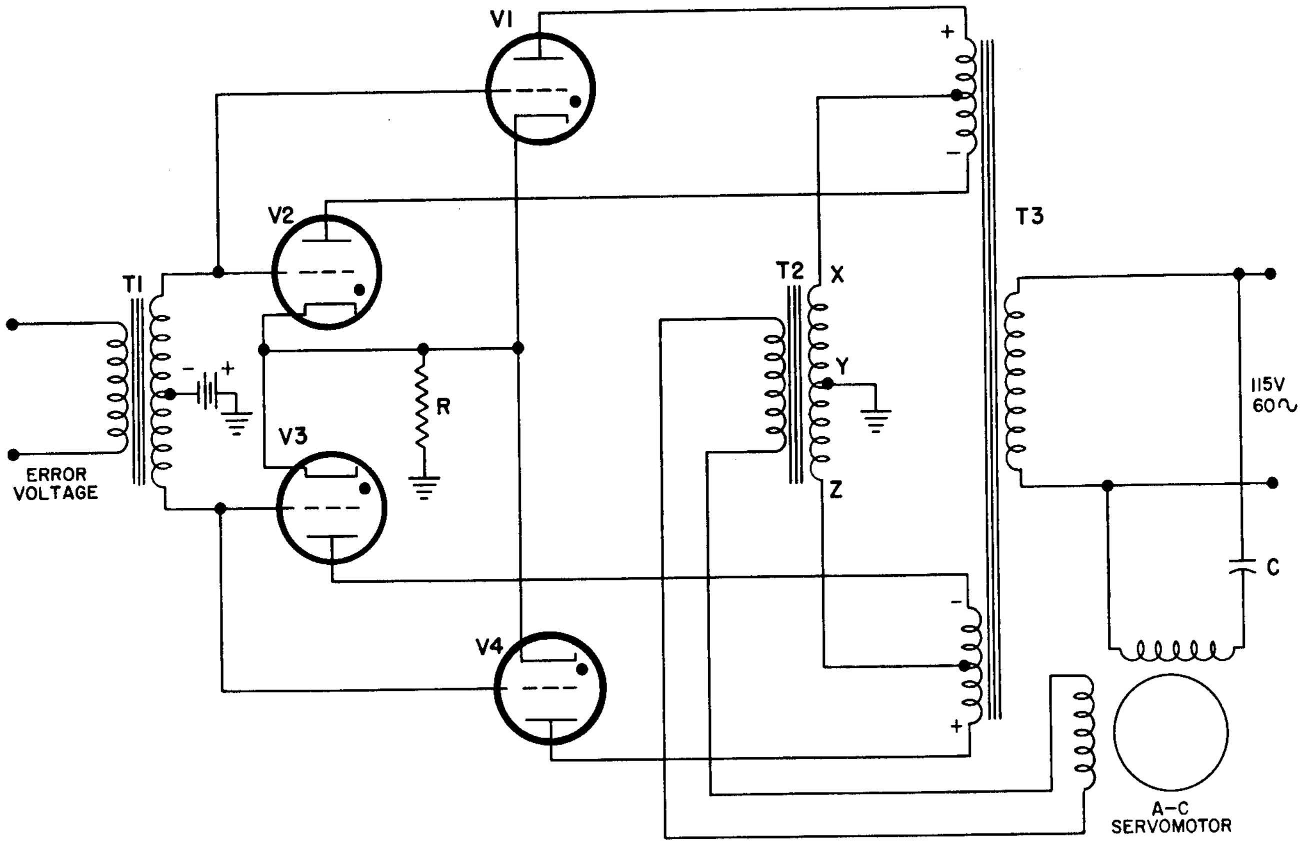


Figure 3-150. Thyratron Control for A-C Servomotor

is reversed in phase, T2 fires on its positive alternations, saturating X2. Point D may now be considered as connected to point C, reversing the servomotor direction of rotation.

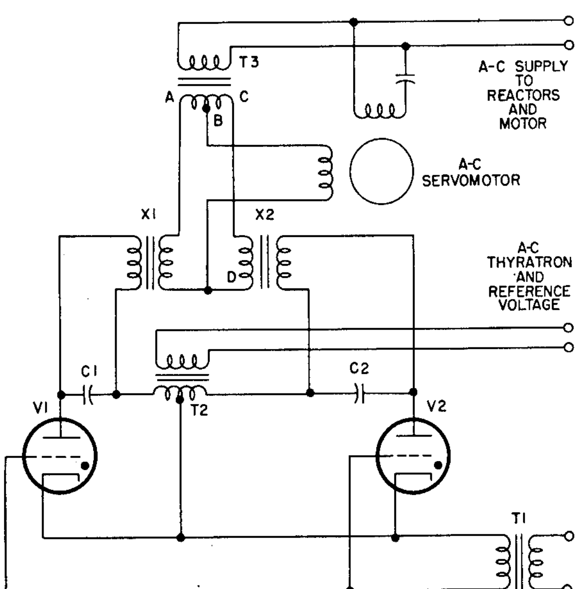


Figure 3-151. Thyratron Saturable Reactor Control for A-C Servomotor

C1 and C2 are shunted across the primary windings of X1 and X2, respectively, and capacitance values are chosen so that the tank circuit is resonant at the reference voltage frequency. Thus, if V1 is the controlling thyratron, C1 acts to supply current to the X1 primary when the thyratron is in its non-conducting half-cycle, and to prevent voltage surges during the conducting half-cycle. This circuit is of particular interest, since it lends itself to a frequency flexibility not usually encountered. Examination of the circuit diagram shows that the error and reference voltages may be of one frequency, while the servomotor and reactor's may be supplied by a voltage of entirely different frequency, without affecting the operation of the control system.

b. AMPLIDYNE CONTROL.—The amplidyne motor-generator consists of a constant-speed a-c drive motor and a two-stage electromechanical power amplifier, contained in a single housing. The drive motor, which may be of the squirrel-cage type, has its rotor shaft coupled to the armature of the generator section. Since this motor drive mechanism is simliar to that of other systems, it can be considered as conventional and, hence, self-explanatory. The amplidyne section, however, is radically different from the conventional generator in the unusual method employed to obtain high

power amplification. The step-by-step development of the amplidyne principle is illustrated in figures 3-152 through 3-156.

A cross section of a conventional d-c generator is diagrammed in figure 3-152. In this representation, a load is shown, drawing a current of 60 amperes from the generator armature. In order to meet this demand, the armature must have induced in it a voltage of sufficient magnitude to force the necessary current to flow. Therefore, the armature conductors must cut a magnetic field of a certain flux density and, in order to provide this flux, a field excitation current of three amperes was found necessary. The generator may now be considered as an amplifier with a current gain of 20. Since the direction of the excitation flux, Φ_e, is from north to south, the flux will pass through the armature core in a horizontal direction, as indicated by the arrows. When the external armature circuit is completed, causing a current flow of 60 amperes, the armature, being wound on an iron core, acts as an electromagnet. This action gives rise to an armature reaction flux, designated in the diagram as Φ_a. If the left-hand rule is applied to the current flow in the armature conductors, the armature flux, Φ_a, is shown to be at right angles to the excitation flux, Φ_e. A simplified version of the circuit is shown in part B of the figure, with flux directions and magnitudes indicated.

Figure 3-153 is the same as figure 3-152 except that, in this case, the load has been removed and the armature leads have been short-circuited. Since the resistance of the load is no longer a factor, the only opposition offered to current flow is the low resistance of the armature windings, plus the negligible resistance of the short-circuit wiring. The immediate result of such a short-circuiting procedure would be to increase the armature current to an abnormally high value. The end result would be a burned out armature. However, one way of reducing the enormous armature current would be to reduce the excitation flux to a much lower level. It is apparent that this flux could be made weak enough so that the short-circuit current in the armature circuit could be reduced to 60 amperes, which it was in the previous example.

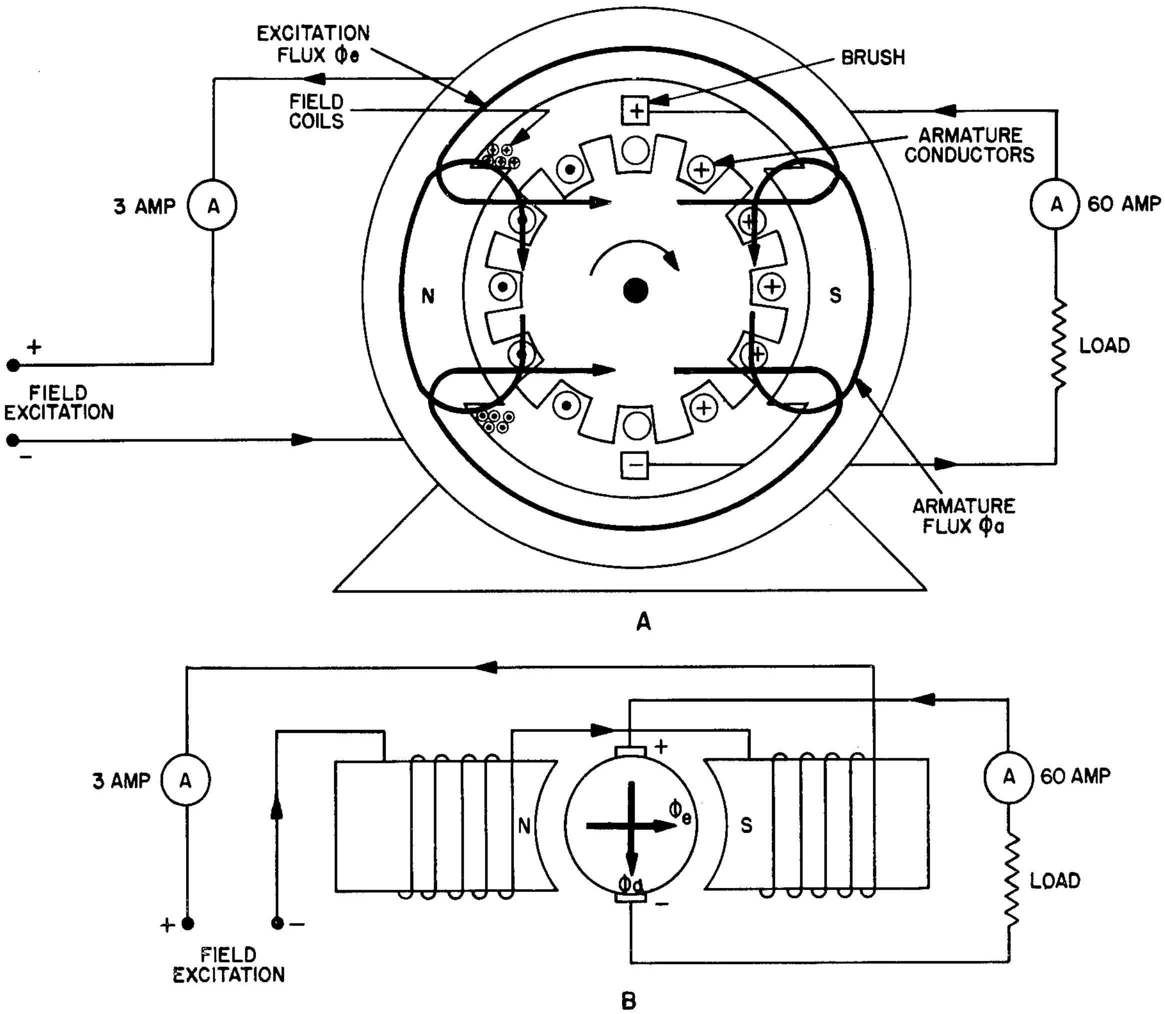
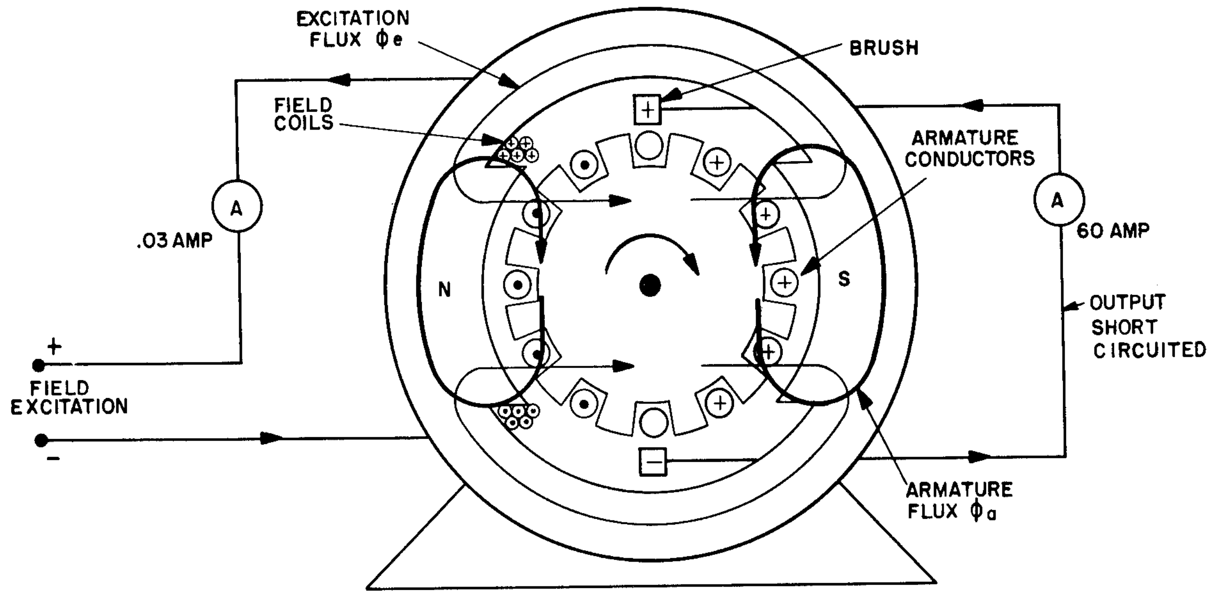


Figure 3-152. Magnetic Field and Current Relationship in Conventional D-C Generator



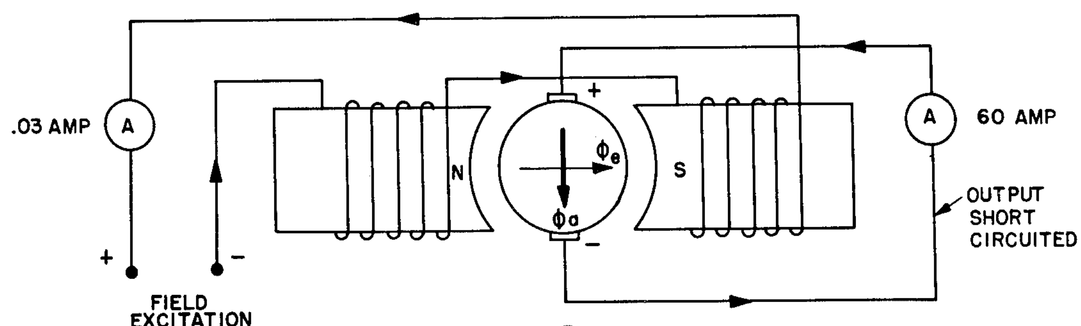


Figure 3-153. Magnetic Field and Current Relationship in Short-Circuited D-C Generator

Moreover, since the armature easily handled a 60-ampere drain in the loaded condition, a short-circuit current of the same value cannot cause damage to it. A reduction in field excitation current will weaken the flux to the proper strength and, in this case, the current has been dropped to .03 ampere. Consequently, it may be seen that .03 ampere of field current controls a short-circuited armature current of 60 amperes, whereas it took three amperes to control the same amount of output current in the loaded state. It is clear, then, that the generator gain has been increased to 2000.

The problem now arises as to how the increased power gain can be put to use. Obviously, the load cannot be placed in series with the short circuit, since this would mean a return to the original status. The short circuit, therefore, must remain intact. From part B of figure 3-153, it is evident that two fluxes exist—a weak field flux, Φ_e, and a strong armature flux, Φ_a, the latter created by a heavy current of 60 amperes. The cross sections show that the armature conductors are evenly spaced around the core; therefore, the conductors will cut across the heavy armature flux, Φ_a, at the same rate as they cut the excitation flux, Φ_e. But the maximum voltage induced in the conductors as they cut the armature flux appears across the armature at right angles to the voltage induced by the excitation flux. To take advantage of this new voltage, caused by the armature conductors cutting their own reaction flux, a second pair of brushes (figure 3-154) is placed on the commutator at right angles to the short-circuited brushes, and connected to the load. Since high amplification is realized as the armature conductors cut the strong reaction flux, Φ_a, the voltage developed across the output brushes is sufficient to supply a large current, e.g., 60 amperes, to the load despite the resistance of the load circuit.

Another problem is encountered here, however, as shown by the diagram. Just as the armature current in the short-circuited section creates a flux at 90 degrees to the excitation flux, so does the current in the output circuit set up a flux at 90 degrees to the armature flux. This new reaction flux, Φ_b, is therefore removed 180 degrees from the original excitation flux, Φ_e. Moreover, flux Φ_b

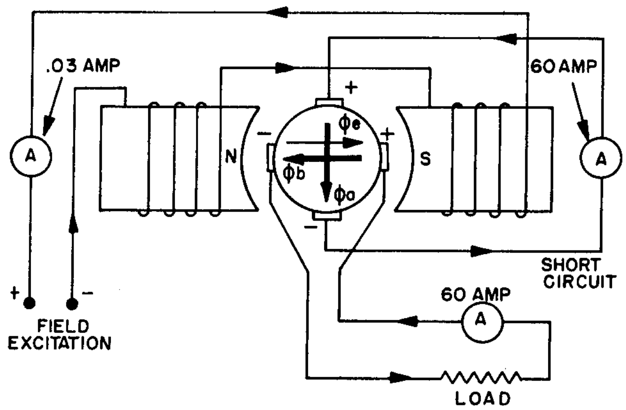


Figure 3-154. Short-Circuited D-C Generator Supplied with Additional Brushes

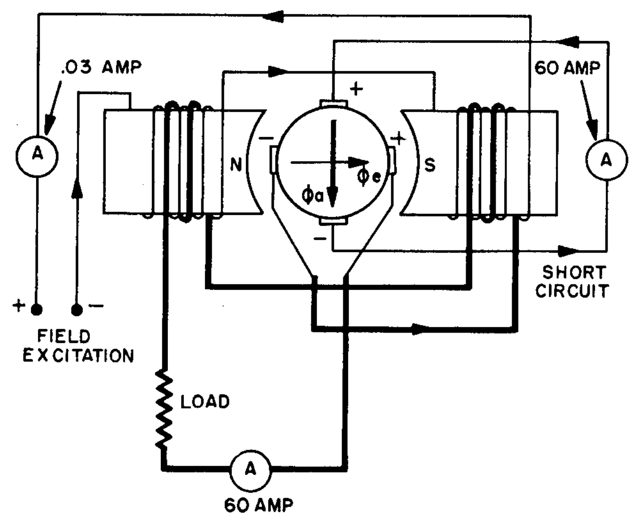


Figure 3-156. Amplidyne Generator Equivalent Circuit, Showing Effective Magnetic Field and Amplification

is very much stronger than excitation flux, Φ_e, and since it is in opposition to Φ_e, the excitation flux could no longer control the output. To overcome this obstacle, a compensating winding is placed on the field pole pieces and is connected in series with the output to the load. In design considerations, the number of turns in this compensating winding is calculated, and the direction of current flow is determined, so that a compensating flux, Φ_c, exactly equal and opposite to flux Φ_b, is developed. The compensating winding and the four flux components are represented in figure 3-155. Inasmuch as Φ_b and Φ_c cancel each other, the resulting fluxes are Φ_e and Φ_a, as indicated in the amplidyne equivalent circuit of figure 3-156.

The original build-up of a voltage in a conventional self-excited d-c generator depends upon a certain amount of residual magnetism existing in the field pole pieces. Some residual magnetism remains in the amplidyne field poles after the field

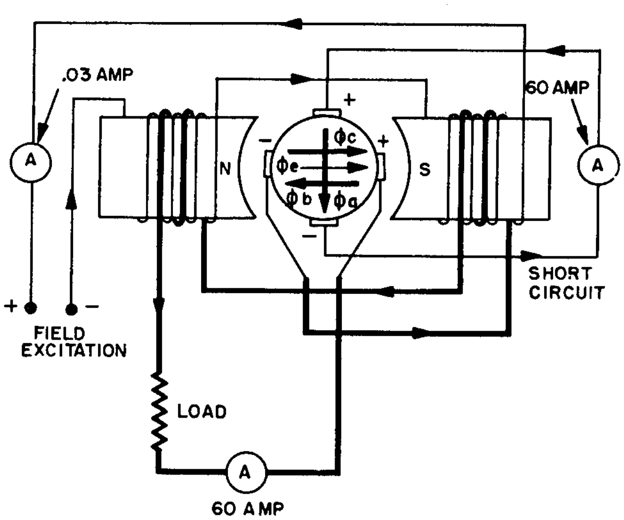


Figure 3-155. Short-Circuited D-C Generator with Additional Brushes and Compensating Winding

excitation current is reduced to zero, which is the proper value when the input and output shafts of the servomechanism are in correspondence. Presence of residual magnetism would cause a weak field flux, resulting in the induction of an appreciable voltage in the armature, because of the amplidyne's high gain. This, in turn, would have the undesirable effect of causing rotation of the servomotor when no error exists. In order to eliminate the residual magnetism, a small a-c generator is used. This generator may consist of a permanent magnet, mounted on the end of the amplidyne armature, and revolving in a small field winding. The output of the a-c generator is applied to two sets of opposed windings placed on the field pole pieces. The effect of these windings is to neutralize the residual magnetism which exists when the field excitation current is zero.

The amplidyne generator can be compared to a two-stage vacuum-tube amplifier. The development of the short-circuit current, with its accompanying armature reaction flux, by means of a small excitation current, constitutes the first stage of amplification. The use of the strong flux, developed by the short-circuit current, to produce a voltage high enough to cause an equally large current to flow through a load circuit, represents the second stage of the system. The second reaction flux, Φ_b, is analogous to negative feedback, or degeneration, in a tube circuit. The compensating winding can be regarded as a regenerative circuit, designed to exactly balance the degeneration so that the net feedback in the amplidyne is zero. Because of its power gain of 10,000, the amplidyne has extensive use in servomechanisms.

c. HYDRAULIC CONTROL.—Hydraulic servomechanisms are used in some radar equipments

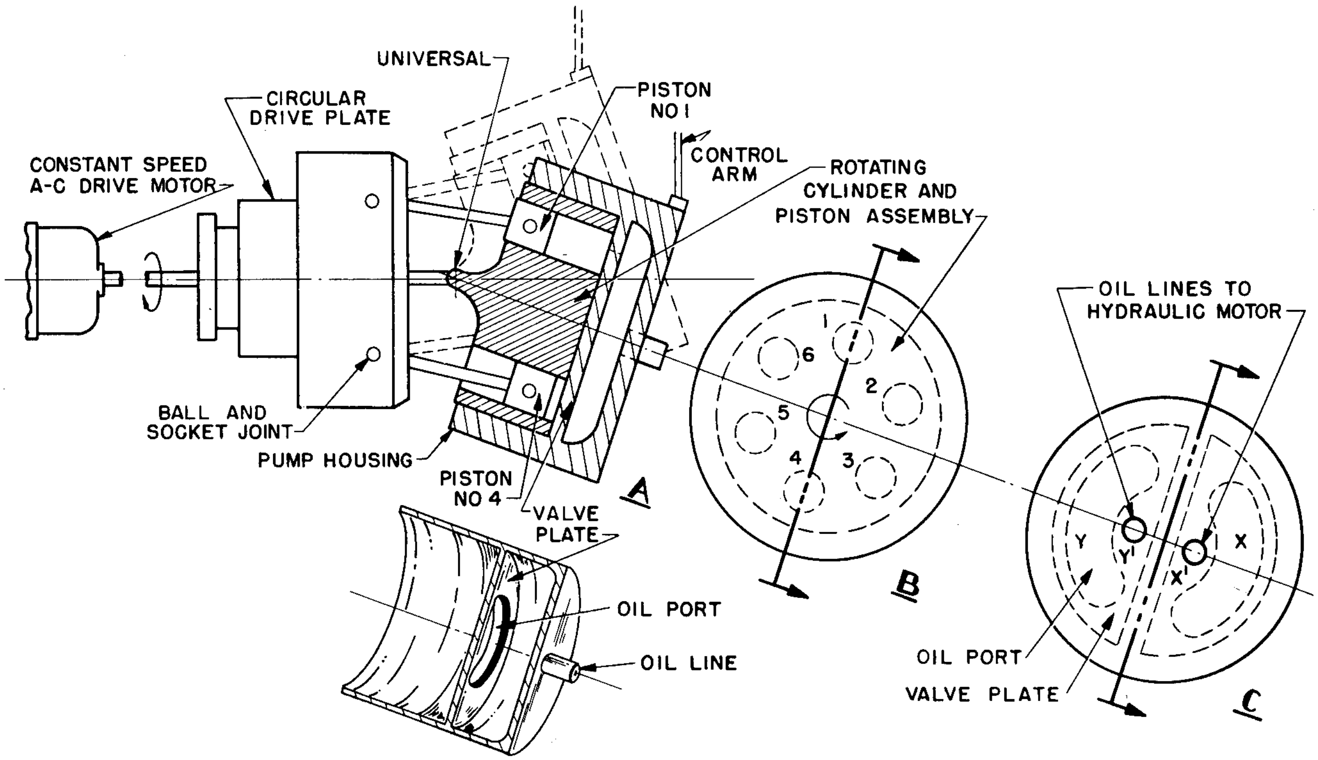


Figure 3-157. Hydraulic Variable-Flow Pump

for antenna positioning, as well as for the positioning of guns and other ordnance equipment. Smaller hydraulic servos find extensive use in specialized military control systems. The hydraulic servomechanism is chosen for many applications where a rapid response, combined with smooth operation, is required. For purposes of explanation, the hydraulic servo components mentioned in the following description are simplified. Actually, such a gun-positioning system would embody many complex refinements. Some of these include either mechanisms, error correctors, coarse-fine data systems with accompanying contact-ring-relay transfer arrangements, limit switches, etc.

(1) VARIABLE-FLOW PUMP.—Figure 3-157 shows a type of variable-flow pump similar to that illustrated in the block diagram of figure 3-158. Figure 3-157 is a cutaway side view of pump mechanism A, a bottom view of cylinder-piston assembly B, and a bottom view of valve plate C. The solid-line portion of A shows the pump housing depressed 30 degrees below the drive shaft. In the dotted-line position, the housing is raised 30 degrees above the shaft axis. Only two pistons and cylinders are indicated in the side view of the sketch. However, there are actually six pistons (in this example), equally spaced in the cylinder block, as shown in B.

In analyzing the operation of the pump, it is assumed that the a-c motor is turning the circular drive plate and the rotating cylinder assembly in a clockwise direction, as indicated by the arrow. At the instant shown, piston 1 is at the top of its stroke and its cylinder is filled with oil, while piston 4 is at the bottom of its stroke, having already pumped its store of oil. By referring to drawing-plate projections B and C, it will be noted that neither piston is pumping at this instant. However, pistons 5 and 6 are over port Y and, since these pistons are moving downward and pushing into their cylinders, oil is pumped into port Y and out of oil line Y. At the same time, pistons 2 and 3, which are aligned with oil port X, are moving upward and pulling out of their cylinders, thereby sucking oil from oil line X into cylinders 2 and 3 through oil port X. In the solid-line pump position, then, Y is the output oil line and X is the input line.

When the control arm pulls the mechanism through the zero-degree position into the top 30-degree position (dotted lines), the pumping action takes place as the pistons move upward. Thus, as the cylinder assembly rotates, the oil is pumped into oil port X. In this condition, X becomes the output oil line, oil is brought into the pump through input line Y, and the direction of oil flow is reversed.

When the pump housing is set in the neutral position, so that it forms no angle with the drive shaft, it is apparent that the cylinder assembly rotates without piston action, since all of the pistons are in the centers of their respective cylinders. Without angular displacement, then, there is

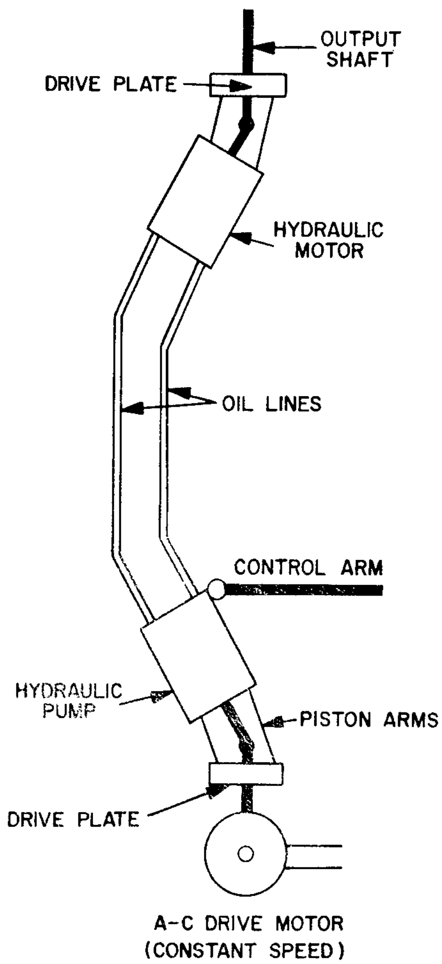


Figure 3-158. Basic Hydraulic Servomechanism

no in-and-out, or pumping action, of the pistons. A condition now exists where each piston cylinder is partially filled with oil, but there is no oil flow, either in or out, through X or Y. It must be stressed that the a-c motor continues to turn the cylinder-piston assembly at all times, even when no pumping action takes place.

Summarizing, the a-c motor turns the variable-flow pump at a constant speed in one direction only. The amount of oil flow is controlled by the angular tilt of the pump housing, maximum flow being realized at 30 degrees. The direction of oil flow may be changed by reversing the pump-housing angle.

(2) HYDRAULIC MOTOR.—The hydraulic motor in the system under discussion is a mechanism exactly like that of the variable-flow pump, except that the pump housing is held fixed at a 30-degree angle to the shaft axis.

In the following analysis of the hydraulic-motor action, the cylinder-piston assembly is assumed to be in the position indicated in figure 3-159. Here again, B represents a bottom view of the rotating assembly, and C is a bottom view of the valve plate. If oil is pumped into the motor through oil line X and oil port X, pressure is exerted on pistons 2 and 3, which, in turn, apply an upward force on the edge of the circular drive plate toward the reader. A clockwise rotation of the load results, as viewed from the end of the output shaft. Oil returns to the variable-flow pump through oil line Y. When the pump angle is reversed, so that oil is pumped through Y into the motor, pistons 5 and 6, which are aligned with port Y, are under

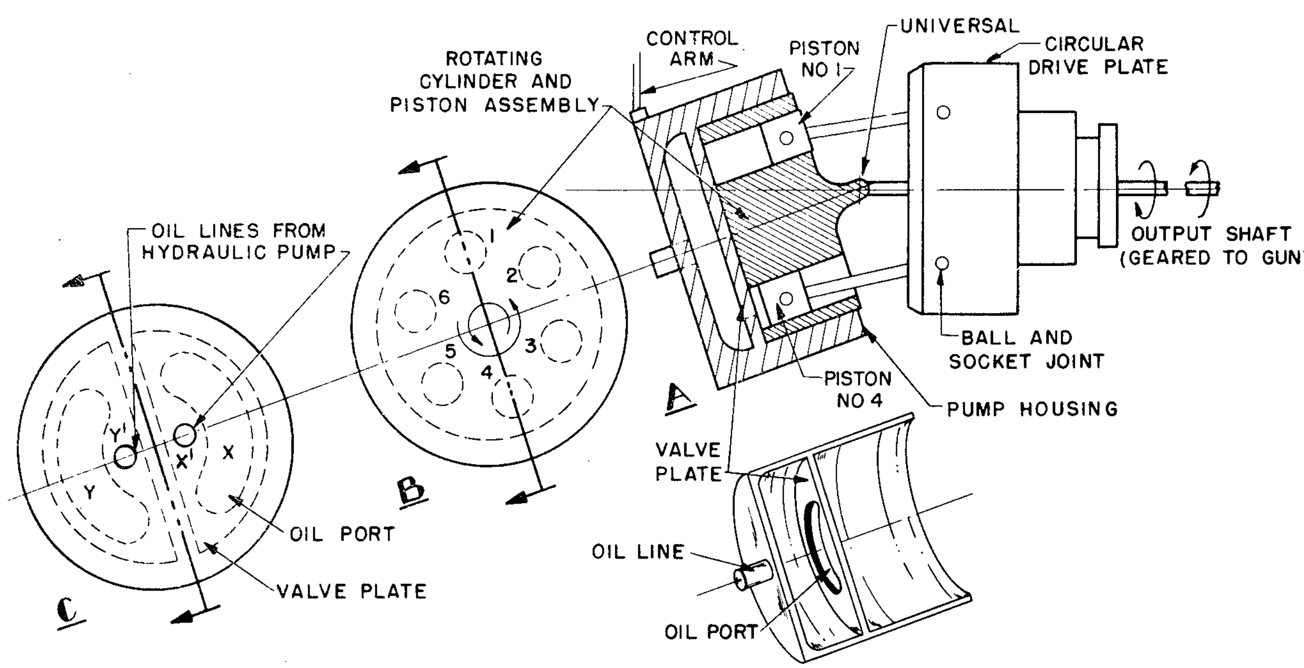


Figure 3-159. Hydraulic Motor

pressure. An upward force is again exerted on the drive plate but, since the force is now applied to the edge away from the reader, the load rotates in a counterclockwise direction.

(3) OIL PRESSURE.—In the variable-speed transmission unit just described, the oil in the system must be held under a certain pressure. This is accomplished by the combination of an oil-replenisher pump and a system of valves which maintain an oil-supply pressure of approximately 75 pounds per square inch to the transmission unit. Maximum hydraulic pressure in the system, controlled by a high-pressure relief valve, is on the order of 1400 psi.

(4) ERROR MEASUREMENT.—It has been shown that the pump is in the neutral, or zero-degree, position when the gun is aimed according to the director order and a no-error condition exists. Furthermore, it is obvious that the angle assumed by the pump housing is a function of the control arm. Therefore, in order to satisfy closed-loop servomechanism requirements, there must be a feedback mechanism linking the gun position to the control arm through an error-measuring device. As in previous instances, there are several error-measuring devices which may be used. In one method, the position of the gun is ordered by a synchro transmitter, located at the gun director and wired to a synchro control transformer at the gun. Completing this type of loop, the shaft of the synchro control transformer is geared to the gun, and the rotor winding feeds the error voltage to a servo amplifier. The amplifier then energizes a servomotor which actuates the pump-housing control arm by means of mechanical or hydraulic linkage. In the variation of this error system, a synchro differential is used as an error detector, supplying enough torque to position mechanically the input member of a hydraulic-booster arrangement. The output piston of the booster is then used to move the arm which controls the angular position of the pump housing. In this system, the differential receives its rotor and stator voltages from the synchro transmitters at the director and gun, respectively.

3-20. RADIAC EQUIPMENT.

a. GENERAL.—Radiac equipment is another type of gear for which the technician, to some extent, assumes responsibility. Because radiac equipment is basically electronic in nature, it falls into the Navy system for design, maintenance, and use of electronic equipment. In general, the repair of radiac equipment can be accomplished with the aid of test equipment available to the technician. Some components, such as subminiature tubes, Geiger-Mueller tubes, and resistors of very high values cannot be thoroughly checked with ordinary testing equipment, and therefore require special consideration. Following a brief outline of the basic types of radiac equipment, the test equipment necessary to check the special components encountered in radiac equipment and to calibrate some radiacmeters will be discussed.

b. CLASSIFICATIONS OF RADIAC EQUIPMENT.—The approved definitions of radiological terms are:

(1) CHARGER, RADIAC DETECTOR.—A device for providing an electrostatic charge to a radiac detector. May include means for measuring the amount of charge.

(2) COMPUTER-INDICATOR, RADIAC.—A device which performs the combined functions of computing and indicating radiac data.

(3) COMPUTER, RADIAC.—A device which receives information from a radiac detector and does one or more of the following: scales, integrates, or counts. Does not indicate.

(4) DENSITOMETER.—An item specifically designed to measure the optical density or opacity of material.

(5) DETECTOR, RADIAC.—A device that is sensitive to radioactivity or free nuclear particles and provides a reaction which can be interpreted or measured by various means.

(6) INDICATOR, RADIAC.—A device which displays radioactivity detection, identification, or computation information.

(7) RADIACMETER.—A device specifically designed to detect and indicate radioactivity. May, or may not, include radiac computer.

(8) RADIAC SET.—All the components and items required for a complete radioactivity detecting and measuring system. May, or may not, include operating spares or the following items: electron tubes, fuses, cable assemblies, power sources, etc.

(9) TRANSMITTING SET, RADIAC DATA. —All the components and items required to detect radioactivity and transmit radioactivity data as modulation on a carrier. May, or may not, include operating spares or the following items: electron tubes, fuses, cable assemblies, power sources, etc.

c. TYPES OF RADIAC EQUIPMENT.—The following is a small sample of the variety of radiac equipments which are used by the Navy. It is by no means a description of all radiac equipments, nor even a complete description of the ones that are mentioned. Its only purpose is to present a general picture of the more commonly encountered equipments, their basic construction, and their functions.

(1) DOSIMETER.—A typical radiacmeter (dosimeter) is the Radiacmeter-Dosimeter IM-9C/PD, figure 3-160. Its function is to measure and indicate the accumulated dose of gamma radiation

Figure 3-160. Radiacmeter-Dosimeter IM-9C/PD

to which the wearer has been exposed. At one end of the radiacmeter is an optical eyepiece, and at the other end is the charging contact. The radiacmeter contains an ionization chamber into which is mounted a small electrometer. A scale calibrated from zero to 200 milliroentgens is mounted in such a manner that the amount of radiation to which the wearer was exposed since the charging of the electrometer can be read directly by holding the radiacmeter up to a source of light and looking into the eyepiece. A radiac-detector charger is required to charge the electrometer. The dosimeter is four inches long and of tubular construction. It is provided with a clip similar to those used on pencils and pens, and may be worn by personnel in a similar manner.

(2) RADIAC SETS.—Two typical equipments are Radiac Sets AN/PDR-18B and AN/PDR-27C. These radiacmeters are portable, hand-carried equipments used to detect and measure the amount of radiation at a particular location. Both are equipped with headphones, a calibrated meter, and a push-button-controlled meter illuminating light, and are supplied with power from internal batteries. The functional difference between these radiacmeters is the degree of radiation they are designed to measure. The AN/PDR-27C is referred to as a "low-intensity" meter, and is calibrated in milliroentgens per hour; the AN/PDR-18B is referred to as a "high-intensity" meter, and is calibrated in roentgens per hour.

(3) RADIATION COUNTERS.—For measurement of gamma radiation in counts per second, an equipment such as Computer-Indicator CP-79/UD may be employed. When used in conjunction with a radiac detector, the computer-indicator forms a counting system, such as the AN/URD-9. For the measurement of gamma radiation in a sample of sea water, the detector is placed in the water and the information from the detector is fed to the computer-indicator, where the amount of radiation from the water sample is indicated in counts per second. The Computer-Indicator CP-79/UD employs a system of indicator lights mounted in six vertical columns, ten lights per column, to visually indicate the counting information. Another similar type of counting equipment is Radiac Set AN/URD-3, which is employed for personnel radiation-surveying. This equipment consists of several subsidiary units mounted in a panel. Both the hands and feet may be simultaneously monitored for gamma radiation by placing them in the openings provided. Six thin-walled, high-voltage Geiger-Mueller tubes provide the detection, while computation is furnished by five scale-of-eight counting circuits, augmented by electric timers and registers. The counting rate is approximately 120,000 counts per minute.

3-21. RADIAC TESTING.

a. GENERAL.—The care and maintenance of radiac equipment entails very little special consideration other than the techniques normally used when testing electronic equipments. There are a few measurements and tests that require specialized test equipment, but the majority of testing can be accomplished with conventional test equipment. The calibration of radiac equipments should be checked at periodic intervals, and requires a known source of radiation for the calibration. This source is available only at radiac equipment repair facilities. These repair facilities are located at various points throughout the country, for instance, at most of the Naval Shipyards; at the Industrial Manager, USN, for the 8th, 9th, 10th, 15th, and 17th Naval Districts; Asst. Industrial Manager, USN, at San Diego, Calif.; and at the U. S. Naval Gun Factory, Washington, D. C.

b. CALIBRATION.—The calibration of radiation detecting equipments are beyond the capabilities of the test equipment available to the technician. Therefore, when calibration of the equipment is required, the services of the nearest radiac repair facility should be requested. The repair facility will have an equipment such as Radiac Calibrator Set AN/UDM-1, figure 3-161, by which accurate calibration of detecting equipment can be made. The AN/UDM-1 is fundamentally a source of radioactivity of known strength. A lead chamber, mounted on a stationary table, contains a capsule of radioactivated cobalt. The capsule is

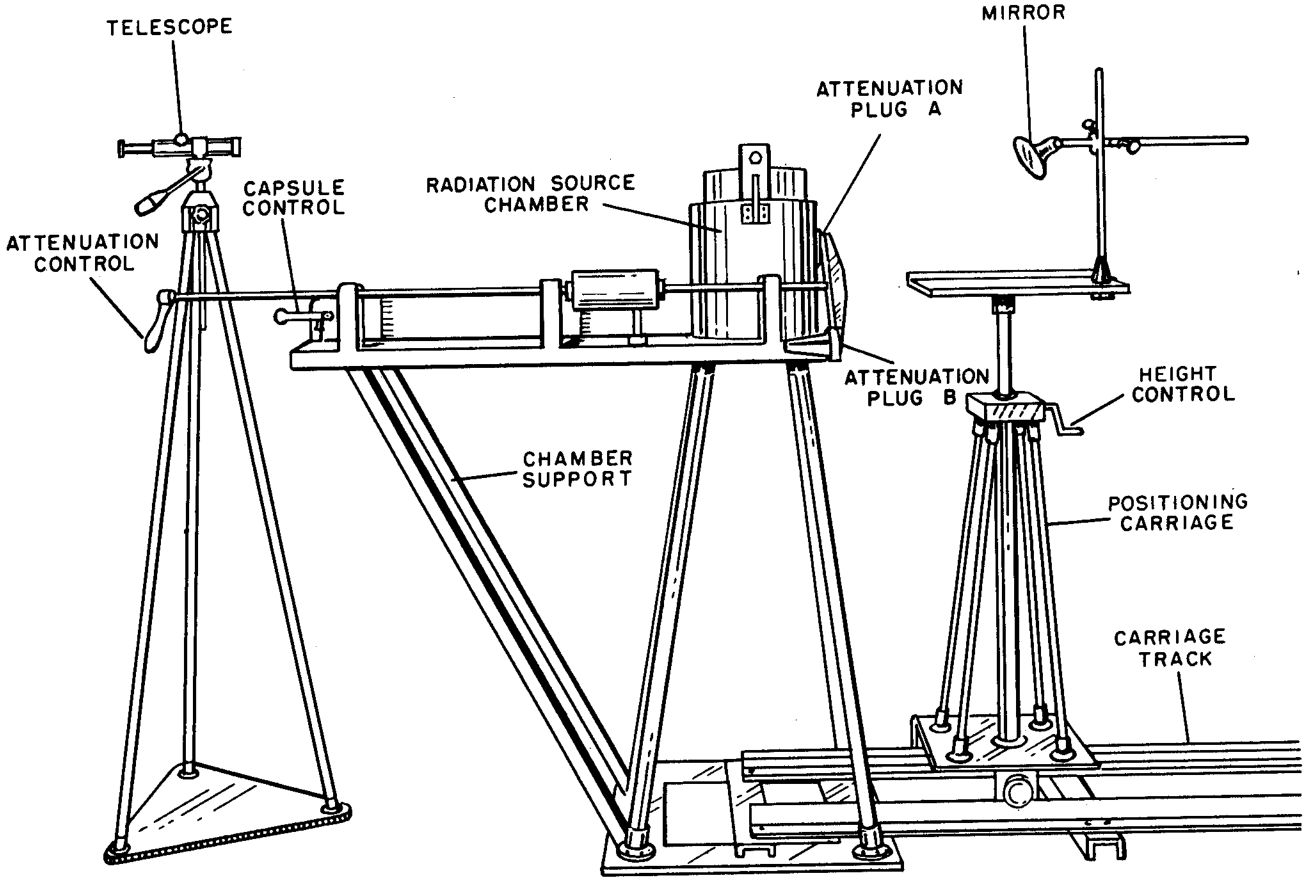


Figure 3-161. Radiac Calibrator Set AN/UDM-1

raised or lowered inside the chamber by an external control. When the capsule is lowered it is in the "safe" position; when raised, it is positioned in front of an opening in the wall of the chamber, and is in the "exposed" position. Mounted on rails directly in front of the source chamber is a movable table. The detecting device to be calibrated is mounted on this movable table, and the table is rolled along the rails until the proper distance between the radiation source capsule and the detecting device is obtained. Two attenuation plugs can be placed in front of the capsule, thereby permitting three degrees of radiation for one particular distance setting. A positioning chart and correction-factor table supplied with the equipment are used to determine the proper distance and attenuator control setting, depending upon the degree of radiation required to calibrate the particular detecting device.

c. OPERATIONAL CHECK OF LOW-INTENSITY RADIACMETERS.—Provided as a component of many low-intensity radiac test sets is a sample source of radiation. It is meant to be used to test the operation of the radiacmeter, and not as a source for calibration. An example of such a test source is Radiation Source MX-1083B/PDR-27, which is supplied as a component of Radiac Set AN/PDR-27C. The test source should be employed as follows:

(1) Energize the radiacmeter and hold the test source (by the clear, uncoated plastic end) perpendicular to, and halfway between the ends, of the external Geiger-Mueller probe.

(2) On the .5-milliroentgen scale, the meter should indicate saturation and return to zero as soon as the test source is moved a foot or two away from the probe. If the meter remains saturated when the test probe is removed, incorrect operation of the radiacmeter is indicated.

(3) With the test source as in step 1, switch to the 5-milliroentgen scale. The meter should indicate between 3 and 4 milliroentgens.

(4) Position the test source perpendicular to the G-M tube which is mounted inside the radiacmeter. On the 50-milliroentgen scale, the meter should indicate between 10 and 15 milliroentgens.

(5) Switch to the 500-milliroentgen scale; the meter should indicate approximately 10 milliroentgens.

d. HIGH RESISTANCE MEASUREMENTS.—Some radiac equipments employ resistors of values up to a megmegohm ($R \times 10^{14}$ ohms). To

measure these extremely high resistances requires specialized test equipment, such as Electron Tube Test Set TV-6/U. The TV-6/U may be used to measure these resistors as follows:

(1) Withdraw the drawer-type compartment on the front, upper left-hand corner of the test set. Fold drawer front panel down.

CAUTION

The body of the resistor should not be handled. When necessary to handle the resistors it should be done by holding the leads at either end. If conditions demand that the body of the resistor be held, a tool such as tweezers should be used.

(2) Place the resistor, figure 3-162, into the tube-resistor holder block so that one lead can be placed under the thumb nut of the Teflon insulated terminal, in the center of the drawer, marked high Z.

(3) Connect the ohm clip (white) to the other end of the resistor. Return drawer securely in place. Set BAT-TEST switch to BAT position and check that batteries are operating properly. Set BAT-TEST switch to TEST position.

(4) Set main selector switch to the approximate range scale required. The main selector switch has eight positions, R $\times$ 10^7 through and including R $\times$ 10^{14}. Place READ-SET switch to SET position. Rotate SET knob until needle on meter falls accurately on the meter scale line marked SET.

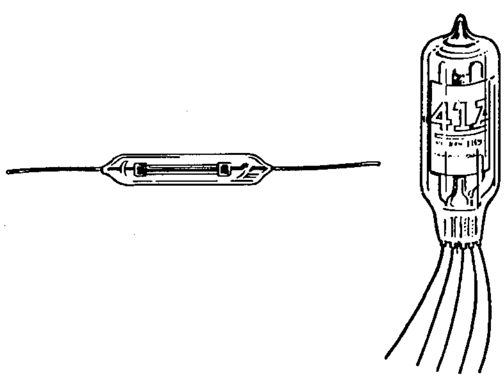


Figure 3-162. ***Subminiature Tube and High Value Resistor***

(5) Set READ-SET switch to READ position. Adjust the PRECISION INDICATOR DIAL until the meter again falls on the SET mark. If the meter indication is too low with the maximum setting of the PRECISION INDICATOR DIAL, the main selector switch should be advanced to the next highest setting and the procedure repeated. Should it be impossible to make the meter fall back to the SET mark, the range being used is too high. The next lower scale should be used, and the procedure repeated.

(6) When the meter indicates properly, read the PRECISION INDICATOR DIAL and multiply the reading by the main selector switch setting. The inner dial of the precision indicator is calibrated in units of 1 to 10; the outer dial is calibrated in tenths and subdivided by hundredths. For example, a reading of 3.78 would be typical.

e. TUBE TESTING.—Because of the use of subminiature, figure 3-162, and Geiger-Mueller tubes in many radiac equipments, the testing of tubes presents a problem to the technician. To test these tubes, specialized tube testers such as Electron Tube Test Sets TV-6/U and AN/USM-23 (TV-9) have been developed. The TV-6/U is designed to test subminiature tubes. The tubes are placed in a compartment in the upper left-hand corner of the front panel. The connections to the tubes are made with a series of leads and clips, each clip having a different color, according to the element to which it is connected. Caution should be used when handling these subminiature tubes. Never hold the tubes near the base of the glass envelope; hold by either the wire leads or the top of the glass envelope. After the tube is properly placed in the tube holder and the leads connected, the correct operating voltage to each individual element of the tube is adjusted by means of the front panel controls. The operating voltages for a particular tube will be found in the instruction book for the equipment from which the tube was removed, or in which it is to be used. The tube tester is capable of measuring both mutual conductance and plate current. The AN/USM-23 (TV-9) equipment is designed to test three specific types of Geiger-Mueller tubes, types BS-1, BS-2, and BS-101. The tubes are inserted in a socket designed to hold the type of tube being measured, and a chart attached to the tube tester furnishes detailed instructions for the testing procedure.

SECTION 4
CARE AND REPAIR OF TEST EQUIPMENT

4-1. LEVELS OF MAINTENANCE—REPAIR FACILITIES.

The levels of maintenance in the Naval service are divided into three general categories: (1) Operational, (2) Technical, and (3) Tender/Yard. These maintenance levels are defined as follows:

a. Operational maintenance will normally consist of inspection, cleaning, servicing, preservation, lubrication, and adjustment as required, and may also consist of minor parts replacement not requiring high technical skill or internal alignment.

b. Technical maintenance will normally be limited to maintenance consisting of replacement of unserviceable parts, subassemblies, or assemblies and the alignment, testing, and adjustment (internal) of equipment.

c. Tender/Yard maintenance is maintenance which requires a major overhaul or complete rebuilding of parts, subassemblies, and/or the end items as required.

These definitions have been approved by competent authority for interservice use; however, the joint, or JAN, terms used are (1) organizational for operational, (2) field for technical, and (3) depot for tender/yard. The full utilization of the first two levels is dependent mainly upon the electronics personnel complement, and the available maintenance parts and tools. When any electronic maintenance or repair work is beyond the capacity of the shipboard level, it becomes necessary to use the other facility. The final, or top, level is tender/yard, where any repair can be effected.

Although the above discussion applies generally to almost all naval electronics equipments, it is reviewed at this time to stress the importance of periodically utilizing the higher levels of maintenance for repair work (or overhaul) involving some test equipments. At the shipboard level of maintenance, caution should be exercised (first, by reading the applicable instruction manual) when repairs are made to any test equipment, because recalibration or realignment involving special equipments may be necessary. In general, when an opportune time arrives, advantage should be taken of the higher maintenance levels to overhaul or repair those equipments which might require special tools, test equipment, etc.

4-2. PREVENTIVE MAINTENANCE.

The electronic technician should constantly keep in mind that the test equipments on which his job performance depends are, for the most part, precision equipments, and must be handled with care if they are to perform accurately their designed functions. To attempt trouble-shooting with unreliable or inaccurate test equipments is frustrating, to say the least, and causes job-performance to become haphazard; therefore, the technician should be extremely careful as to the handling of any test equipment that must be used in the maintenance program. Before attempting to operate a test equipment, the instruction manual or other pertinent literature should be carefully read. Particular attention should be paid to that part of the text which describes the limitations of the equipment, and to any special precautions that must be observed to prevent damage to the equipment.

Some equipments may require special handling; however, there are several precautions which apply to test equipments in general. Rough handling, moisture, and dust all affect the useful life of such devices. Bumping or dropping a test instrument, for example, may destroy the calibration of a meter or short circuit the elements of an electronic tube within the instrument. Creasing or denting coaxial test cables will alter their attenuating effect, thereby affecting the accuracy of any r-f measurements made with these cables in the circuit.

The effects of moisture are minimized in many of the more complicated electronic test equipments, such as signal generators, oscilloscopes, etc, by utilizing built-in heaters which should always be operated for several minutes before applying the high voltage to the equipment. Although most test equipments are now tropicalized, to reduce the danger of high-voltage breakdown as a result of moisture absorption, some of the components of the equipments, such as variable capacitors, switches, relays, tube sockets, etc, cannot be so treated. To reduce the danger of corrosion to these untreated parts, always store such test equipment in a dry place when it is not in use. Excessive dust and grime inside a test equipment also affects its accuracy. Be sure that all the assembly screws which hold the case of the test

equipment in place are tightened down securely. As an added precaution, all dust covers should be placed on test equipments when they are not in use.

Meters are the most delicate parts of test equipments. In order to ensure that the meter will maintain its accuracy, these additional precautions should be followed: (1) make certain that the amplitude of the input signal under test is within the range of the meter; (2) keep meters as far away as possible from strong magnets; and (3) when servicing a test equipment, disconnect the meter from the circuit before making resistance or continuity tests. The latter precaution will eliminate the possibility of burning out the meter.

Preventive maintenance consists of anticipating possible troubles which if not corrected would lead to inopportune test-equipment breakdowns. Primarily, this program comprises periodic inspection, and cleaning of contacts and components. Certain suggestions can be made for such a program; however, local conditions will determine to some degree the exact details.

The responsibility for maintenance of test equipment rests upon the shipboard technician, either partly or entirely, as was explained in paragraph 4-1. A preventive-maintenance program for shipboard test equipments that is set up from information provided in individual instruction manuals should be kept in continuous operation at the operational and technical level. This program, in addition to correcting possible troubles and taking routine care of the test equipments, should be augmented by a plan to utilize effectively the higher-level services which have the necessary tools and equipments for the specialized maintenance required for most test equipments, e.g., that type of service and repair that requires readjustment, realignment, and calibration. Such a supplementary plan or program will, of course, be dictated to some degree by such exigencies as time and place. It is suggested that the routine test-equipment maintenance charts include semiannual or annual checks, and at these periods it should be noted whether or not a test equipment requires higher-level maintenance. The period when a ship is scheduled for general overhaul at a tender, yard, or base is an appropriate time to have any necessary higher-level maintenance work performed.

The instructions for properly stowing test-equipment cables and other accessories, as set forth in the instruction manuals accompanying the equipment, should be carefully read and strictly adhered to. Improper stowage of accessories results in changes in cable characteristics, intermittent cables and leads, and, in general, causes unreliable test-equipment indications.

4-3. CORRECTIVE MAINTENANCE.

The shipboard electronic and fire-control technician is limited to some extent in the corrective maintenance that he is able to perform on test equipments (and still have them function accurately and reliably), principally because he does not have the tools and equipment, and sometimes, the spare parts, necessary for this specialized form of maintenance. Therefore, the technician should realize the limitations imposed upon the repair of certain test equipments, and in no case should he attempt repairs until the applicable instruction book has been thoroughly read, particular note being made of possible circuit misalignment or need for recalibration resulting from parts replacement. In the corrective-maintenance sections of some test-equipment instruction manuals, trouble-shooting charts are provided for the localization of trouble. When these charts are supplied, they should be utilized for the correction of any trouble. However, for test equipments not supplied with the trouble-shooting charts, several methods of trouble analysis (including some hints and kinks) are discussed in the text immediately following the general discussion on test-equipment trouble-shooting.

a. TEST EQUIPMENT TROUBLE-SHOOTING—GENERAL.—A few preliminary tests, along with a logical procedure, often serve to locate the source of trouble without the use of extensive test equipment. In many cases, the reported symptoms along with a few astute observations will indicate the type and probable location of the trouble. Make observations carefully, and keep the symptoms constantly in mind.

The use of the senses of smell, sight, hearing, and touch often localize the source of trouble rapidly. Note unusual odors, such as: sealing compound, which could indicate an overloaded transformer; scorched paint, which could indicate an overheated resistor; and burning rubber, which might point to defective insulation. If any component emits any unusual odor, the trouble may be in that part or in the associated circuit. Examine for smoking parts or sparking. Note if wax-impregnated capacitors have lost any wax—usually indicative of a defective capacitor. Depending, of course, upon the type of test equipment that is faulty, hum, scratch noises, and other odd sounds should have special meaning to the technician. In general, certain sounds are associated with certain types of trouble. For instance, if the test equipment has a power supply an audible output hum may indicate an open or shorted filter capacitor. If variable capacitors are used, scratch noises, heard when the tuning control is varied, may indicate dirty rotor contacts or foreign particles caught on the plates of the tuning capacitor. The operation of the filaments may be checked by touching the tubes after the test equipment has been operating for a short time. The equipment should then be turned off, and the different parts, such as re-

sistors, transformers, and capacitors, should be touched cautiously so as to determine if there is overheating.

WARNING

Capacitors in high-voltage circuits, as in oscilloscopes, should be discharged after turning off the power.

b. METHODS OF TROUBLE ANALYSIS.—In the isolation of trouble, the following methods may be utilized. The particular advantages of each method will be discussed separately. However, no test method can be effective, unless it is used logically and systematically. These methods are: (1) visual inspection, (2) load-resistance testing, (3) shock testing, (4) tube testing, (5) point-to-point analysis, and (6) signal tracing.

(1) VISUAL INSPECTION.—In addition to some of the items covered in paragraph 4-3.*a.*, visual inspections should be made of the following: (1) power supply and fuses, (2) seating of tubes in their sockets, (3) input and output connections, (4) positions of switches and panel controls, (5) all parts for evidence of burning or charring, and (6) variable capacitors for shorted plates.

(2) LOAD-RESISTANCE TESTING.—If the test equipment uses a power supply, measure the resistance (make certain the power is off) between the rectifier filament (or cathode) and chassis (or B minus). The normal resistance indication is between 15,000 and 200,000 ohms. If a somewhat low resistance reading is encountered, a short (or partial short) may be present somewhere in the d-c operating circuit. Consult the schematic diagram supplied with the instruction manual, keeping in mind that the defective part could be a shorted filter or by-pass capacitor. (Note: If the above trouble is indicated, do not apply power to the test equipment until repair has been effected.)

(3) SHOCK TESTING.—The shock test is a static test method, and, since it may be made without entirely dismantling the test equipment, it is usually one of the first tests to be made. In making such a test, the tubes are removed (or tapped) and then reinserted, one at a time, exposed grid caps are tapped, etc., until the troublesome stage is found. Any stage which produces an abnormal indication should be suspected of being defective. Caution must be exercised when using this method, because a certain amount of experience is necessary in order to interpret properly the "sounds" or other indications that shock testing produces. Nevertheless, this method is a time saver, and can be used to advantage provided extreme care is exercised until accumulated experience permits more rapid job performance.

(4) TUBE TESTING.—If the shock test indicates the possibility of a faulty tube, that tube should be tested, preferably on a transconductance-type tube tester. If a tube tester is not available, the suspected tube should be replaced with a new one. If operation is not restored, then all tubes should be tested. Because differences in interelectrode capacitances could cause misalignment, all tubes should be marked so that they may be reinserted in the same sockets. If operation of the test equipment is not restored, then the next method of analysis must be tried.

(5) POINT-TO-POINT ANALYSIS.—This method is used in whole or in part, depending upon the experience of the technician and the availability of detailed information on voltage and resistance measurements (records or charts). Most test equipments are supplied with sufficient information to permit the technician to compare a few strategically chosen (from experience) voltage or resistance readings with those indicated in the charts, and to locate the trouble quickly. The less experienced technician obtains the same end result, although he may have to take many more tedious and time-consuming readings.

(6) SIGNAL TRACING.—On certain test equipments, an effective stage-by-stage test can be made by signal tracing. In many respects, this method is similar to the shock test described earlier, but is far more accurate and should be used by the less experienced technician. The principle, of course, is to localize the trouble by permitting a signal of the correct frequency to be passed through an individual stage while the output is observed. If there is no output (or, as is usually the case, if the output is extremely low), it follows that the stage must be defective. One method, sometimes called sensitivity testing, is to feed a signal of the correct frequency into the input of a stage, and measure the output, or amplification, by means of an electronic voltmeter or dynamic analyzer. When the faulty stage is found, point-to-point analysis (either voltage or resistance) is then used to locate the defective part or component.

SECTION 5
REFERENCE DATA

5-1. GLOSSARY OF TERMS.

A SCAN (A DISPLAY)—In RADAR, a display in which targets appear as vertical deflections from a line representing a time base. Target distance is indicated by the horizontal position of the deflection from one end of the time base. The amplitude of the vertical deflection is a function of the signal intensity.

ABSORPTION FREQUENCY METER (WAVEMETER)—A frequency-measuring device incorporating a variable tuned circuit which absorbs a small portion of the radiated energy under measurement.

AMPLITUDE MODULATION (AM)—Modulation in which the amplitude of a carrier is the characteristic varied. (Refer to paragraph 2-9.-*a.*(1).

ANGULAR FREQUENCY—The frequency expressed in radians per second. It is equal to the frequency in cycles per second multiplied by 2π.

ANTI-HUNT DEVICE—A device used in positioning systems to prevent hunting or oscillation of the load around an ordered position. The device may be mechanical or electrical. It usually involves some form of feedback.

AQUADAG—A suspension of fine carbon particles in water. (See SAND LOAD.) When an insulating surface is painted with aquadag and allowed to dry, the surface becomes a conductor.

ARTIFICIAL ECHO—A reflection of the transmitted pulse back to the source from an artificial target, such as an echo box, corner reflector, or other metallic reflecting surface. Also the delayed signal from a pulsed r-f signal generator.

ATMOSPHERIC ABSORPTION—The attenuating effect of atmospheric gases and moisture in the atmosphere on the propagation of microwaves (most noticeable at wavelengths below 3 centimeters). (Refer to paragraph 3-11.*d.*(2)(*b*)*4.*)

ATTENUATOR — A device, either fixed or variable, which is used to reduce the amplitude of a signal.

AUTOMATIC FREQUENCY CONTROL—An arrangement whereby the frequency of an oscillator is automatically maintained within specified limits.

AUTOMATIC GAIN CONTROL—A circuit arrangement which adjusts the gain in a specified manner in response to changes in input.

AUTOMATIC VOLUME CONTROL—A system which tends to maintain a constant-amplitude output despite variations in the amplitude of the input signal.

AVERAGE POWER—A value of power equal to the time integral of the instantaneous peak power divided by the time of integration. (Refer to paragraph 3-9.*a.*)

B SCAN (B DISPLAY)—In RADAR, a rectangular display in which targets appear as illuminated areas with bearing indicated by the horizontal coordinate and distance by the vertical coordinate.

BARRETTER—A bolometer consisting of an appropriately mounted short length of very fine wire, usually platinum, or a metallic film which has a positive temperature coefficient of resistance. (Refer to paragraph 3-5.*c.*(3).)

BEACON, RADIO—A facility, usually a non-directional radio transmitter, emitting identifiable signals intended for radio direction finding observations.

BEACON TRANSMITTER — An automatic transmitter which, when triggered by a radar signal from a remote aircraft or ship, transmits a coded signal, thus enabling the aircraft or ship to determine its azimuth and range with respect to the beacon.

BIDIRECTIONAL COUPLER—A device with two outputs, designed for insertion in a waveguide system. It simultaneously samples and presents at one output a voltage that is largely a function of the wave traveling in one direction and at the other output a voltage that is largely a function of the wave traveling in the opposite direction.

BLANKING PULSE—A pulse used to remove the lines that would otherwise be traced on a cathode-ray tube during the retrace, or flyback, time (the time during which the electron beam returns to start another line or trace).

BOLOMETER—A small resistive element used in the measurement of low and medium r-f power. It is characterized by a large temperature coefficient of resistance which is capable of being properly matched to a transmission line. The barretter and thermistor are widely used bolometers. (Refer to paragraph 3-5.*c.*(3).)

CARRIER SHIFT—A condition resulting from imperfect modulation which causes a change of carrier power in amplitude modulation.

CARRIER SWING—The total deviation of an FM or PM wave from the lowest instantaneous frequency to the highest instantaneous frequency.

CASCADE—In series, as tuning circuits or amplifier stages used one after another.

CAVITY RESONATOR—A space normally bounded by an electrically conducting surface in which oscillating electromagnetic energy is stored, and whose resonant frequency is determined by the geometry of the enclosure.

CHARACTERISTIC IMPEDANCE—Usually expressed as the impedance which an infinitely long transmission line would present at its input terminals (in a lossless line, the characteristic impedance is equal to L/C). A line will appear to be infinitely long if terminated in its characteristic impedance.

CLASS A AMPLIFIER — An amplifier in which the grid bias and alternating grid voltages are such that plate current in a specific tube flows at all times.

CLASS B AMPLIFIER—An amplifier in which the grid bias is approximately equal to the cutoff value, so that the plate current is approximately zero when no exciting grid voltage is applied, and so that plate current in a specific tube flows for approximately one half of each cycle when an alternating grid voltage is applied.

CLASS C AMPLIFIER—An amplifier in which the grid bias is appreciably beyond the cutoff value, so that the plate current in each tube is zero when no alternating grid voltage is applied, and so that plate current flows in a specific tube for appreciably less than one half of each cycle when an alternating grid voltage is applied.

COAXIAL-LINE FREQUENCY METER — Shorted section of coaxial line which acts as a resonant circuit and is calibrated in terms of frequency or wavelength.

CROSSTALK—A phenomenon in communications whereby the intelligence of one communication channel modulates, and thus is superimposed on, another channel.

DAMPING—1. The reduction of Q of a resonant circuit by increasing the losses of the circuit. 2. The exponential decay of the amplitude in an oscillating circuit or wave.

DBM—Decibels relative to one milliwatt. Power greater than one milliwatt is indicated by prefixing a plus sign; power less than one milliwatt is indicated by prefixing a minus sign.

DECIBEL—The decibel is one-tenth of a bel, the number of decibels denoting the ratio of the two amounts of power being ten times the logarithm to the base 10 of this ratio. The abbreviation db is commonly used for the term decibel.

DETECTION (DEMODULATION)—A process of rectification by which intelligence is recovered from a modulated wave.

DIFFERENTIATING CIRCUIT — A circuit which produces an output voltage substantially in proportion to the rate of change of the input voltage or current. Differentiating circuits employ short time constants compared to the time duration of the pulse applied.

DIFFRACTION — Slight bending of a radio wave caused by contact of the wave with the surface of the earth or with some other conducting mass.

DIRECT WAVE—A wave that is propagated directly through space.

DIRECTIONAL COUPLER—A device used to extract a portion of the r-f energy moving in a given direction in an r-f transmission line. Energy moving in the opposite direction is rejected.

DISCRIMINATOR—A circuit in which the output is dependent upon how an input signal differs in some aspect from a standard or from another signal.

DOUBLE MODING — Frequency-shifting, or jumping, of a magnetron; changing abruptly from one frequency to another, at irregular intervals.

DUMMY ANTENNA—A device which has the necessary impedance characteristics of an antenna and the necessary power-handling capabilities, but which does not radiate or receive radio waves.

DUMMY LOAD—A dissipative but essentially nonradiating substitute device.

DUTY CYCLE (PULSE)—The ratio of the pulse time to the period of pulse occurrence.

ECHO BOX—A high-Q resonant cavity used with microwave radar sets to provide an artificial target for radar testing and for tuning receiver to transmitter. The echo box stores r-f energy which is received through a pickup antenna during the transmitted-pulse interval, and reradiates this energy through the same antenna for a short time immediately after the pulse.

EHF (EXTREMELY HIGH FREQUENCY)—30,000 to 300,000 megacycles (.01 to .001 centimeter).

ELECTRICAL ZERO—A standard reference position from which all rotor angles are measured. This standard establishes the correct settings for all the synchro units in a system.

ERROR-RATE DAMPING—A type of damping in which servo control is accomplished by two voltages—one proportional to the error, and the other proportional to the rate at which the error changes. Also known as proportional plus derivative control.

ERROR VOLTAGE—A voltage which is present in a servo system when input and output shafts are not in correspondence. The error voltage, which actuates the servo system, is proportional to the angular displacement between the two shafts.

FIDELITY—The degree with which a system, or a portion of a system, accurately reproduces at its output the essential characteristics of the signal which is impressed upon its input.

FIELD STRENGTH, ELECTRIC (MAGNETIC)—The magnitude of the electric (magnetic) field vector.

FREQUENCY—Frequency is the number of recurrences of a periodic phenomenon in unit time. In specifying electrical frequency, the customary unit of time is the second.

FREQUENCY DEVIATION — In frequency modulation, the peak difference between the instantaneous frequency of the modulated wave and the carrier frequency.

FREQUENCY DISTORTION — A term commonly used for that form of distortion in which relative magnitude of the different frequency components of a complex wave are changed in transmission.

FREQUENCY MODULATION—Angle modulation in which the instantaneous frequency of a sine-wave carrier is caused to depart from the carrier frequency by an amount proportional to the instantaneous value of the modulating wave.

FRONTS—Boundaries considered to exist between dissimilar air masses.

GATING—Applying a rectangular voltage to the grid or cathode of a cathode-ray tube to sensitize it during the sweep time only.

GEARED SYNCHRO SYSTEM—A system in which the transmitting and receiving synchros turn at a higher speed than the input and output shafts. Geared systems are generally used when a high degree of accuracy is required.

GRASS—In RADAR, a descriptive colloquialism used to refer to indication of noise on an "A" or similar type display.

GRID-DIP METER—A multiple-range oscillator incorporating a meter in the grid circuit to indicate grid current. The instrument is so named because the meter reading "dips" when an external resonant circuit is tuned to the oscillator frequency.

GROUND-REFLECTED WAVE — A radio wave that is reflected upward from the ground at a slight angle.

GROUND WAVE—A radio wave that is propagated over the earth and is ordinarily affected by the presence of the ground and the troposphere. The ground wave includes all components of a radio wave over the earth except ionospheric and tropospheric waves. (Note: The ground wave is refracted because of variation in the dielectric constant of the troposphere, including the condition known as a surface duct.)

HARMONIC DISTORTION—Nonlinear distortion characterized by the appearance in the output of harmonics other than the fundamental component when the input is sinusoidal.

HETERODYNE DETECTOR—A detector incorporating a local oscillator (called a beat-frequency oscillator), used to convert an incoming r-f signal to an audible tone by the heterodyning process.

HETERODYNE FREQUENCY METER — A frequency measuring device that heterodynes the unknown signal with an internally produced signal of known frequency. The difference frequency, usually within the audible range, is then measured if it is not zero.

HETERODYNING—The process of combining two signals of different frequencies in a nonlinear device, thereby producing a number of new frequencies. Of these, there are two main frequencies, one being equal to the sum of the original frequencies, and the other to their difference. Heterodyning ordinarily makes use of the difference-frequency signal (beat) only.

HORN RADIATOR—A radiating element having the shape of a horn.

IMAGE FREQUENCY — In superheterodyne reception, an image frequency, for any given point in the tuning range, is that frequency which is higher, or lower, than the local-oscillator frequency (higher, if the oscillator frequency is higher than the desired signal frequency; lower, in the opposite case) by an amount equal to the intermediate frequency.

IMAGE RATIO—The ratio of (1) the field strength at the image frequency to (2) the field strength at the desired frequency, each field being applied in turn, under specified conditions, to produce equal outputs.

INDUCTION FIELD—Electric and magnetic field energy that is alternately stored in the space surrounding a conductor and then returned to the circuit. (See RADIATION.)

INTENSITY MODULATION (Z-AXIS MODULATION)—The technique of applying a signal to the grid of a cathode-ray tube, so that the brightness of various portions of the pattern will be varied accordingly.

INTERMODULATION DISTORTION — Impairment of fidelity resulting from the production of frequencies that are the sum of, and the difference between, frequencies contained in the applied waveform. (Refer to paragraph 3-6.*d.*(6).)

IONOSPHERE—The uppermost portion of the atmosphere, characterized by regions of varying degrees of ionization (called Heaviside layers).

K BAND—A band of frequencies in the vicinity of 24,000 megacycles (1.25 centimeters). (Refer to paragraph 5-3.)

KEEP-ALIVE ELEMENT—An auxiliary electrode in a TR tube, to which a negative d-c potential is applied to ensure the presence of enough ions to allow an almost instantaneous discharge across the spark gap when the transmitter pulse occurs, thus preventing r-f leakage through the TR switch.

L BAND—A band of frequencies in the vicinity of 1000 megacycles (30 centimeters). (Refer to paragraph 5-3.)

LECHER WIRE—A transmission line which uses the characteristics of standing waves for the determination of wavelength at the higher frequencies.

LIMITER—A transducer whose output is constant for all inputs above a critical value.

LINEAR AMPLIFIER—An amplifier in which the signal output voltage is directly proportional to the signal input voltage.

LINEAR DETECTOR—A detector that produces an a-f output signal directly proportional in amplitude to the variations of the r-f input. (Variations in the amplitude of an AM wave, or variations in the frequency of an FM wave.)

LISSAJOUS PATTERN—The figure described by a point which is simultaneously displaced by two simple harmonic motions at right angles, when the periods of the two motions are in the ratio of two whole numbers.

LOSSY LINE—Transmission line with a high degree of attenuation. Example: RG-21/U uses a Nichrome center conductor and has a loss of about 1.6 db per foot in the X band. (RG-9/U has a loss of about .3 db per foot in the X band.)

LUBBER LINE—A prominent, fixed reference line in a compass, directional gyro, etc. Also, a reference line, parallel to the long axis of a ship or aircraft, from which readings are made.

MAGNETIC CIRCUIT—The path of the flux as it travels from the north pole through the circuit components and back to the north pole. In a generator, the magnetic circuit components include the field yoke, field pole pieces, air gap, and armature core. The magnetic circuit may be compared to the electrical circuit, with magnetomotive force corresponding to voltage, flux lines to current, and reluctance to resistance. Thus, Ohm's law for the magnetic circuit may be expressed as $\Phi = F/R$, where Φ = number of flux lines expressed in maxwells, F = magnetomotive force expressed in gilberts, and R = reluctance of the circuit in cgs units.

MAGNETRON—An electron tube characterized by the interaction of electrons with the electric field of a circuit element in crossed steady electric and magnetic fields to produce a-c power output.

MAGNETRON ARCING—Internal breakdown between cathode and anode of a magnetron (usually resulting from bursts of gas). Arcing occurs during the breaking-in, or "seasoning", period and again at the end of the useful life. Occasional arcing is to be expected, and is more common in high-power magnetrons.

MAGNETRON PULLING—Frequency shift of a magnetron as a result of mismatch of the r-f lines. Pulling is caused by such factors as faulty rotating joints, reflections from near-by objects to the antenna, etc.

MAGNETRON PUSHING—Frequency shift of a magnetron as a result of faulty operation of the modulator. Pushing may be caused by an improperly shaped pulse or by interaction of the pulse with the magnetic field of the magnetron.

MICROPHONICS — Electrical noise voltages developed by mechanical vibration.

MICROWAVES—Radio waves in the frequency range of 1000 to 30,000 megacycles or in the wavelength range of 30 to 1 centimeters.

MINIMUM DISCERNIBLE SIGNAL (MDS) —The receiver input power level that is just sufficient to produce a visible signal in the receiver output; used as a receiver sensitivity test. (Refer to paragraph 3-10.*a.*)

MODE JUMP—Change in mode of magnetron operation from one pulse to the next. (Each mode represents a different frequency and power level.)

MODE SHIFT—Change in mode of magnetron operation during a pulse.

MODE SKIP—Failure of magnetron to fire on each successive pulse.

MODULATION—The process or result of the process whereby some characteristic of one wave is varied in accordance with another wave.

MODULATION FACTOR—The ratio of the peak variation actually used to maximum design variation in a given type of modulation.

MODULATION INDEX—In angle modulation, the maximum phase deviation of the carrier.

MULTIPLIER (METER)—A device, generally used in series or parallel with a meter to extend its measuring range beyond that for which the instrument alone is suitable.

NEGATIVE RESISTANCE — A condition whereby an increase in the current passing through a device is accompanied by a decrease in the voltage drop across the device.

NOISE—An undesired disturbance within the useful frequency band.

OVER-ALL SYSTEM PERFORMANCE — A term used to describe the range capability of a radar system. Over-all system performance depends upon three factors: (1) the transmitted power, (2) the loss in the propagating medium, and (3) the minimum discernible received signal. (Refer to paragraph 3-11.*d.*)

PARASITIC OSCILLATIONS — Unintended self-sustaining oscillations, or transient impulses.

PEAK POWER—The power at the maximum of a pulse of power, excluding spikes.

PERCENTAGE MODULATION—The modulation factor expressed as a percentage.

PERIOD—The time corresponding to one cycle of periodic phenomenon.

PERMANENT ECHO—An echo received from a structure or a land mass, such as a mountain, which does not change position.

PHASE—The angular difference between two sine waves of the same frequency; equal to the product of the angular frequency and the time interval between the instants at which the amplitude of each wave is zero.

PHASE (DELAY) DISTORTION — Impairment of fidelity as a result of nonlinear phase characteristics, which cause various frequencies of an applied waveform to be delayed disproportionately.

POLARIZATION, DIRECTION OF — For a linearly polarized wave, the direction of the electric vector.

POWER FACTOR — The cosine of the phase angle between the voltage applied to a load and the current passing through it (sometimes the cosine is multiplied by 100 and expressed as a percentage).

POWER STANDING-WAVE RATIO—The ratio of power maxima to power minima. It is determined by the load impedance and the characteristic impedance of the propagation medium.

PPI SCAN—A cathode-ray indicator in which a signal appears on a radial line. Distance is indicated radially and bearing as an angle.

PULSE REPETITION FREQUENCY — The pulse repetition rate of a periodic train of pulses.

PULSE TRANSFORMER—A transformer of special design which operates over a wide range of frequencies. (The frequency range must include the PRF and the desired harmonics.)

Q (FIGURE OF MERIT)—The ratio of 2 times the maximum energy stored in a circuit to the energy lost per cycle.

RADAR RECEIVER NOISE FIGURE (NF)—The ratio of (1) noise power measured at the output of the receiver to (2) noise power which would be present at the output if the thermal noise due to the resistive component of the source impedance (at temperature of 290° Kelvin) were the only source of noise in the system. For heterodyne systems, the (2) noise power includes only that noise from the input termination which appears in the output via the principal frequency transformation of the system, and does not include spurious contributions such as those from image-frequency transformations.

RADIATION—1. The process of emission of electromagnetic energy that propagates through space. 2. Propagating electromagnetic energy in space.

RADOME—A dielectric housing for an antenna.

RATIO DETECTOR—A type of FM detector that uses current opposition from the diodes to generate the signal. The detector also incorporates amplitude limiting and thus can be used without a limiter preceding the detector.

RECEIVER BANDWIDTH—The number of cycles per second expressing the difference between the limiting frequencies of the receiver pass band characteristics.

RECOVERY TIME OF RADAR RECEIVER—The time required, after the end of a saturating signal, for the receiver sensitivity to return to half its maximum value.

REFLECTION—1. The return or change in direction of particles or waves after impinging on a surface without passing through the surface. 2. In a transmission line, the return of the incident wave or portion thereof by improper match of the termination or by an electrical discontinuity in the transmission line.

RESIDUAL MAGNETISM — The amount of flux remaining in an iron core after the magnetizing current is reduced to zero.

RESONANCE—Resonance is a condition which exists in a circuit containing inductance and capacitance when its equivalent reactance is zero. When the inductance and capacitance are connected in series, the current in the circuit is maximum. When the inductance and capacitance are connected in parallel, the external current is approximately a minimum.

RETRACE—The path traced by the electron beam in a cathode-ray tube in going from the end of one line to the start of the next line or trace.

R-F PROBE—A device which is used to extract r-f energy from a transmission system.

RING TIME — In RADAR, the time during which the output of an echo box remains above a specified level. The ring time is used in measuring the performance of radar equipment.

ROTATING JOINT—A device for permitting one section of a transmission line to rotate (or oscillate) continuously with respect to another and still maintain a matched impedance.

S BAND—A band of frequencies in the vicinity of 3000 megacycles (10 centimeters). (Refer to paragraph 5-3.)

SAND LOAD—A section of waveguide which is used as a terminating section and which dissipates power. The dielectric space in the line is filled with a sand-and-aquadag mixture which acts as a matched-impedance load, thus preventing the generation of standing waves.

SELECTIVITY—Selectivity of a radio receiver is that characteristic which determines the extent to which it is capable of differentiating between the desired signal and disturbances of other frequencies.

SENSITIVITY—The lowest signal input capable of causing an output signal having desired amplitude characteristics.

SERIES FEED—A method of connecting an oscillator or tuned-amplifier circuit in which direct current flows through some portion of the inductive part of a tuned circuit.

SERVO OSCILLATION—An unstable condition in which the load tends to hunt back and forth about the ordered position.

SHF (SUPER HIGH FREQUENCY)—3000 to 30,000 megacycles (10 to 1 centimeters).

SHOT EFFECT—Noise voltages developed as a result of the random nature of electron travel within electron tubes. The effect is characterized by a steady hiss in audio reproduction, and by "snow" or "grass" in video reproduction.

SHUNT FEED— A method of connecting an oscillator or tuned-amplifier circuit in which no direct current flows through any portion of the inductive part of a tuned circuit.

SIGNAL-TO-NOISE RATIO—The ratio of the value of the signal to that of the noise.

SINGLE-SIDEBAND TRANSMISSION—Single-sideband transmission is that method of operation in which one sideband is transmitted and the other sideband is suppressed. The carrier wave may be either transmitted or suppressed.

SMITH CHARTS—A series of transmission-line charts in polar plot form used for the interpretation of measured values of VSWR or reflection coefficients. It can also be used for determining the effect of a discontinuity (or a change in characteristic impedance) and for solving impedance-matching problems. (Refer to paragraph 5-5.)

SPACE ATTENUATION (SPACE LOSS)—A power loss, expressed in db, of a signal in free space, caused by such factors as absorption, reflection, scattering, and dispersion.

SPACE WAVE—Radiated energy consisting of the direct and ground waves.

SPECTRUM — 1. The entire range of wavelengths (or frequencies), within which electromagnetic radiations occur, bounded at one end by the longest radio waves and at the other by shortest known cosmic rays. 2. A segment of wavelengths which has a special function or possesses special properties. For example, the radio spectrum extends from about 20,000 cps to over 30,000 megacycles, and the light spectrum, changing gradually from deep red at one end to violet at the other, lies approximately at the middle of the over-all spectrum. Within the radio spectrum there are the very-low frequency, low-frequency, medium-frequency, etc., spectra (plural of spectrum). 3. A graph or display of frequency vs power.

SPECTRUM ANALYZER—A test instrument which is used to plot energy intensity versus frequency over a band of frequencies.

SQUARE-LAW DETECTOR — A detector which makes use of the parabolic (square law) characteristic for detection.

SUPERHETERODYNE RECEIVER — A receiver that performs superheterodyne reception, which is a form of heterodyne reception in which one or more frequency changes take place before detection.

SWEEP—1. A term designating the wave applied to either set of deflecting plates (or coils) of a cathode-ray tube, usually the horizontal plates (coils), for the purpose of deflecting the electron beam in a prescribed manner. For example, a saw-tooth sweep is a waveform in which the increase of voltage (or current) is a linear function of time. 2. A term designating a signal, the instantaneous frequency of which changes from a lowest value to a highest value, or vice versa, usually at a linear rate.

SYNCHROSCOPE—A type of oscilloscope with a nonrecurrent triggered sweep.

SYSTEM SENSITIVITY—Ratio of transmitter power output to receiver sensitivity; may be expressed in terms of db or power ratio.

THERMAL AGITATION — Minute voltages, arising from random electron motion which are a function of absolute temperature (degrees Kelvin).

THERMISTOR—A bolometer characterized by a decrease of resistance as the temperature rises. (See BARRETTER.)

THERMOCOUPLE — A device consisting of two dissimilar metals in physical contact, which thereby form a thermo-junction across which a voltage is developed when the junction is heated. An instrument comprising a thermocouple, or thermocouples, connected to a meter calibrated in units of temperature is one of many types of pyrometers (used to measure high temperatures). A thermocouple heated by r-f current and connected to a d-c meter serves as an r-f ammeter when the meter is calibrated in amperes, and as an r-f voltmeter when the meter is calibrated in volts.

TORQUE—That which produces, or tends to produce, rotation. Torque is equal to the applied force multiplied by the distance from the center of rotation. Example: if a wheel has spokes 3 feet long, and a force of 4 pounds is applied tangentially at the end of a spoke, the torque exerted to turn the wheel is 12 foot-pounds.

TORQUE GRADIENT—The torque required in inch-ounces to pull a specific energized synchro 1 degree away from its normal position.

TRANSDUCER—A transducer is a device capable of being actuated by waves from one or more transmission systems or media and of supplying continuously related waves to one or more other transmission systems or media.

TRANSIT TIME — The time required by an electron to travel from the cathode to the plate of an electron tube.

TRANSMISSION LINE—A device which conveys radio-frequency energy from one point to another.

TRAVELING DETECTOR—An r-f probe together with a detector; used to measure SWR in a slotted-line section.

UHF (ULTRA HIGH FREQUENCY)—300 to 3000 megacycles (1 meter to 10 centimeters.)

UNBLANKING PULSE—A pulse applied to the grid or cathode of a cathode-ray tube to sensitize the tube for a particular length of time, normally the time of one sweep. The application of the pulse for this purpose is called gating.

UNIT TORQUE GRADIENT — The torque gradient of a synchro, measured when the synchro is electrically connected to another synchro of the same size.

VELOCITY ERROR—The amount of angular displacement existing between a servo-mechanism's input and output shafts when both are turning at the same speed.

VOLTAGE-STANDING-WAVE RATIO (VSWR)—The ratio of voltage maxima to voltage minima on a transmission line.

VOLTMETER SENSITIVITY—The ratio of the total resistance of the voltmeter to its full-scale reading in volts, expressed in ohms per volt.

VOLUME UNIT—A volume unit is a unit used to specify the audio-frequency power level in decibels above a reference level of 1 milliwatt. A volume unit is equal to a decibel only when changes in power are involved or when the decibel value has this same reference level. The reference level of 1 milliwatt need not be mentioned when dealing in volume units, as it is a part of the definition.

WAVEFRONT—The plane containing the electric and magnetic fields of radiated energy.

WAVELENGTH—The distance traveled by a propagated wave during a time corresponding to one cycle. (Wavelength in meters equals 300 divided by the frequency in megacycles, for radio waves traveling through space.)

X BAND—A band of frequencies in the vicinity of 10,000 megacycles (3 centimeters). (Refer to paragraph 5-3.)

ZERO ERROR—A term used to indicate the delay time occurring within the transmitter and receiver circuits of a radar system. For accurate range data, this delay time must be compensated for in the calibration of the range unit.

5-2. RADIO FREQUENCY CLASSIFICATIONS.

The following table gives radio frequency classifications that have been assigned by the Federal Communications Commission.

TABLE 5-1. RADIO FREQUENCY CLASSIFICATIONS

BAND	FREQUENCY SPECTRUM (KC)	WAVELENGTH IN METERS
VLF (Very Low)	10—30	30,000—10,000
LF (Low)	30—300	10,000—1,000
MF (Medium)	300—3,000	1,000—100
HF (High)	3,000—30,000	100—10
VHF (Very High)	30,000—300,000	10—1
UHF (Ultra High)	300,000—3,000,000	1—.1
SHF (Super High)	3,000,000—30,000,000	.1—.01
EHF (Extremely High)	30,000,000—300,000,000	.01—.001

5-3. RADAR FREQUENCY BANDS.

The following table gives present-day radar band classifications.

TABLE 5-2. RADAR FREQUENCY BAND CODE LETTERS

BAND P

	FREQ	λ
	0.225 0.390	133.3 76.9

BAND L

SUB	FREQ	λ
P	0.390 0.465	76.9 64.5
C	0.465 0.510	64.5 58.8
L	0.510 0.725	58.8 41.4
Y	0.725 0.780	41.4 38.4
T	0.780 0.900	38.4 33.3
S	0.900 0.950	33.3 31.6
X	0.950 1.150	31.6 26.1
K	1.150 1.350	26.1 22.2
F	1.350 1.450	22.2 20.7
Z	1.450 1.550	20.7 19.3

BAND S

SUB	FREQ	λ
E	1.55 1.65	19.3 18.2
F	1.65 1.85	18.2 16.2
T	1.85 2.00	16.2 15.0
C	2.00 2.40	15.0 12.5
Q	2.40 2.60	12.5 11.5
Y	2.60 2.70	11.5 11.1
G	2.70 2.90	11.1 10.3
S	2.90 3.10	10.3 9.68
A	3.10 3.40	9.68 8.83
W	3.40 3.70	8.83 8.11
H	3.70 3.90	8.11 7.69
Z	3.90 4.20	7.69 7.15
D	4.20 5.20	7.15 5.77

BAND X

SUB	FREQ	λ
A	5.20 5.50	5.77 5.45
Q	5.50 5.75	5.45 5.22
Y	5.75 6.20	5.22 4.84
D	6.20 6.25	4.84 4.80
B	6.25 6.90	4.80 4.35
R	6.90 7.00	4.35 4.29
C	7.00 8.50	4.29 3.53
L	8.50 9.00	3.53 3.33
S	9.00 9.60	3.33 3.13
X	9.60 10.00	3.13 3.00
F	10.00 10.25	3.00 2.93
K	10.25 10.90	2.93 2.75

BAND K

SUB	FREQ	λ
P	10.90 12.25	2.75 2.45
S	12.25 13.25	2.45 2.26
E	13.25 14.25	2.26 2.10
C	14.25 15.35	2.10 1.95
U	15.35 17.25	1.95 1.74
T	17.25 20.50	1.74 1.46
Q	20.50 24.50	1.46 1.22
R	24.50 26.50	1.22 1.13
M	26.50 28.50	1.13 1.05
N	28.50 30.70	1.05 0.977
L	30.70 33.00	0.977 0.909
A	33.00 36.00	0.909 0.834

BAND Q

SUB	FREQ	λ
A	36.00 38.00	0.834 0.790
B	38.00 40.00	0.790 0.750
C	40.00 42.00	0.750 0.715
D	42.00 44.00	0.715 0.682
E	44.00 46.00	0.682 0.652

BAND V

SUB	FREQ	λ
A	46.00 48.00	0.652 0.625
B	48.00 50.00	0.625 0.600
C	50.00 52.00	0.600 0.577
D	52.00 54.00	0.577 0.556
E	54.00 56.00	0.556 0.536

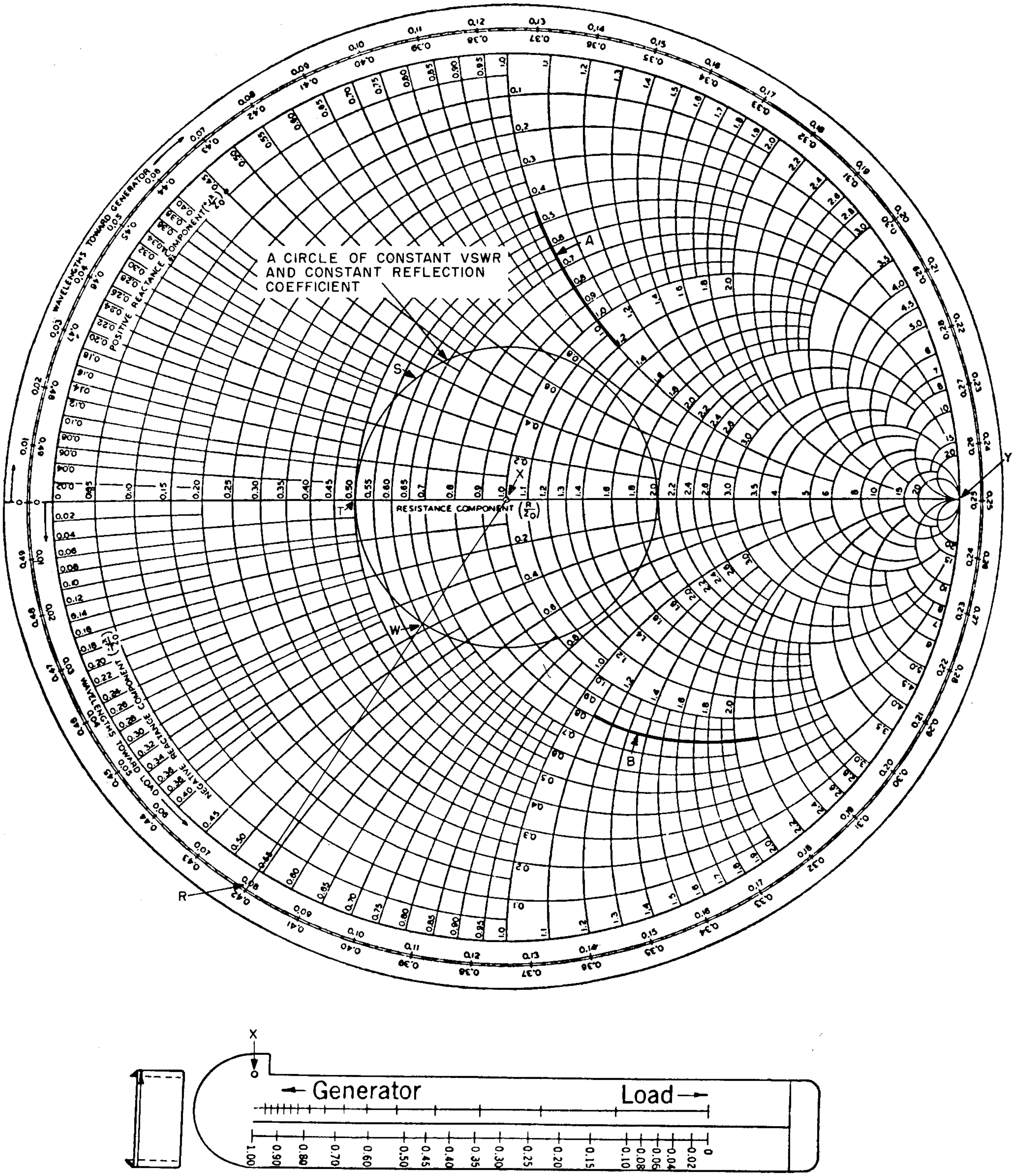


Figure 5-1. Smith Chart

5-4. TEST EQUIPMENT BIBLIOGRAPHY.

A list of test equipment publications, a brief description, and fleet distribution, is provided in EMB, chapter 3, to aid electronic personnel in choosing the right type of test equipment.

5-5. SMITH CHARTS.

Interpretation of some measurements made in transmission lines and waveguides may be made on a Smith chart. This form of transmission line chart is a polar plot, consisting of a system of impedance coordinates, superimposed upon which is another system of lines representing loci of constant standing-wave ratio, and constant distance along the line. The chart may be used for the interpretation of the measured values of VSWR and the location of the voltage minima in terms of equivalent input impedance (or admittance) circuits, or in terms of reflection coefficients. It is also useful for determining the effect of a discontinuity or a change in characteristic impedance, and for solving impedance-matching problems.

Point X, figure 5-1, at the center of the chart is the origin for a polar plot of the reflection coefficient, the angle being indicated on the circular scale around the rim, and the magnitude by the radial distance measured outward from the center on a scale graduated linearly from 0 to 1. Circular arcs such as A extending from point Y to the outer rim are the loci of all reflection coefficients that correspond to normalized impedances having equal reactive parts; for circle A the impedances have reactance of 1.0. Circles such as B represent reflection coefficients corresponding to normalized impedances having equal resistive parts; for circle B this resistance is 0.8.

When traversing a standing-wave circle (S) with a standing-wave ratio of 2.0, the resistance axis is crossed at two points, one giving a very high resistance and the other a very low resistance. These correspond to the voltage maxima and minima, respectively, observed on a standing-wave detector. On the basis of this, the Smith chart can be used in connection with the standing-wave detector to determine unknown load impedances. For example, a standing-wave ratio of 2.0 (circle S) is observed, and the first voltage minima is 0.08 wavelength (R) from the load. Starting at point T, which corresponds to the voltage minimum at a standing-wave ratio of 2.0, travel along this circle S of constant standing-wave ratio toward the load to the point where the line drawn between points R and X intersect circle S. At this point of intersection W, read the coordinates of the load impedance, which in this example are 0.62 — j0.38. Multiplying these numbers by the characteristic impedance of the standing-wave detector gives the actual impedance of the terminating load.

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